EVALUATION OF VITICULTURAL IMPACTS ON 3-ISOBUTYL-2-METHOXYPYRAZINE CONCENTRATIONS IN *VITIS VINIFERA* L. CV. CABERNET FRANC

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EVALUATION OF VITICULTURAL IMPACTS ON 3-ISOBUTYL-2-METHOXYPYRAZINE CONCENTRATIONS IN *VITIS VINIFERA* L. CV. CABERNET FRANC

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Studies were conducted in New York State to identify the major environmental and viticultural factors that influence 3-isobutyl-2-methoxypyrazine (IBMP) evolution in grapes and to develop management strategies to control IBMP levels.

Partial least squares regression was used to model the concentration of IBMP in berries at 50 days after anthesis (DAA, accumulation) and log-fold decrease in IBMP concentration from 50 DAA to harvest (degradation) as a function of viticultural and environmental data collected from multiple Cabernet franc vineyards (10 in 2008 and 8 in 2009). The most important predictors for modeling IBMP accumulation were factors associated with vine vigor, and higher vigor was positively correlated with IBMP accumulation. IBMP degradation could not be satisfactorily modeled across multiple sites, but within sites, factors associated with vine vigor, crop to vine size, and fruit maturity were important predictors. In the warmer growing season (2008), IBMP concentrations at 50 DAA (range 2008 = 103 to 239 pg/g; range 2009 = 12 to 87 pg/g) were significantly higher than 2009 at all 8 sites. IBMP degradation was less in the cooler growing season, but harvest concentrations (range 2008 = 1 to 13 pg/g; range 2009 5 to 14 pg/g) were not significantly different between years at 5 out of 8 sites as a result of lower preveraison accumulation.

Basal leaf removal treatments imposed preveraison reduced IBMP concentrations in Cabernet franc (34 to 88%) and Merlot (38 to 52%) berries at

harvest, but postveraison treatments were not efficacious. Shoot tipping and chlormequat treatments applied to Cabernet franc vines during the preveraison period altered vine growth and canopy density, but did not affect IBMP concentrations in berries at harvest. Clonal selection was evaluated as a potential tool to manage IBMP, but the Cabernet franc clones under study (1, 214, 312, 327) did not possess distinct characteristics that consistently resulted in differential vine growth and IBMP concentrations.

These experiments suggest that high IBMP concentrations are likely to occur in vigorous sites where high preveraison temperatures are followed by poor ripening conditions. Preveraison basal leaf removal and managing for vine balance are potential strategies to control IBMP levels.

BIOGRAPHICAL SKETCH

Justin Scheiner was born in La Marque, Texas. He graduated from Normangee High School in May 1999. Justin received a Bachelor of Science degree in Horticulture and Crop Science from Sam Houston State University in May 2005. In May 2007, he received a Master of Science degree in Molecular and Environmental Plant Sciences from Texas A&M University. Upon completion of his M.S., Justin entered the Ph.D. program at Cornell University in the Department of Horticulture. Following the completion of his Ph.D., he plans to return to Texas.

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CHAPTER 1

LITERATURE REVIEW

Introduction

Premium wines produced in cool climates such as New York State are usually associated with a balance of flavors. However, in poor years, red wines can have excessive “herbaceous” aromas that suppress fruity characters and generally detract from wine quality. Research has identified a class of potent odorants, the methoxypyrazines (MPs), as the primary contributor of wine herbacousness in Cabernet franc and other Bordeaux winegrape cultivars. At concentrations near sensory detection threshold, MPs are thought to enhance wine quality by adding complexity and in some cases, varietal character. At higher concentrations however, MPs can dominate wine flavor with aromas that are often associated with unripe fruit. Based on their potential to influence wine quality, MPs have been the focus of numerous viticultural and enological studies. Results of these studies suggest that MP evolution in grape berries is influenced by a complex interaction of climatic and physiological factors. To date, the actual relationship between these factors and MPs is not well understood resulting in few viable vineyard control strategies. Because MPs cannot be selectively removed from wine through conventional enological practices, it has been proposed that the most effective way to reduce MPs in wine is to reduce the concentration in developing fruit. Identifying specific viticultural factors that most directly influence MP concentrations in grape berries will lead to more effective management practices thus increasing the sustainability of the cool climate wine production.

3-Alkyl-2-methoxypyrazines

The 3-alkyl-2-methoxypyrazines (MPs) are a class of heterocyclic, aromatic compounds produced by a variety of horticultural crops (Murray and Whitfield 1975). In plants, the most abundant MPs are 3-isobutyl-2-methoxypyrazine (IBMP), 3-isopropyl-2-methoxypyrazine (IPMP), and 3-secbutyl-2-methoxypyrazine (sBMP) (Murray and Whitfield 1975, Rizzi 1990). IBMP, the first MP identified, is described as having an aroma characteristic of bell pepper (Buttery et al. 1969, Parliament and Epstein 1973, Seifert et al. 1970). The aroma of IPMP is described as peas, raw potatoes, and earthy aroma, and sBMP is described as peas, pea shells, and galbanum oil (Buttery et al. 1969, Buttery and Ling 1973, Murray and Whitfield 1975, Murray et al. 1970, Parliament and Epstein 1973, Seifert et al. 1970). In water, the detection threshold of MPs ranges from 0.5 to 2 ng/L (Buttery et al. 1969, Seifert et al. 1970). Vegetative tissues and fruits of plants such as bell pepper (*Capsicum annuum*) can produce MP concentrations that exceed the sensory threshold by 3 orders of magnitude (Murray and Whitfield 1975).

The biosynthetic pathway of MPs has not been elucidated in plants. However, several pathways have been proposed. Murray et al. (1970) and Murray and Whitfield (1975) suggest that a variety of substituted pyrazines, including MPs, can form naturally by the condensation of α-amino acids with α,β-dicarbonyl compounds. The putative pathway suggests that IPMP, sBMP, and IBMP are derived from the branch chain amino acids valine, leucine, and isoleucine, respectively, with a pyruvic aldehyde and/or pyruvate as the α,β-dicarbonyl compound. Although it has not been validated in plants, studies confirm this metabolism in bacteria (Cheng et al. 1991, Gallois et al. 1988). Recent work in grapes indicates that the final step IBMP and IPMP synthesis involves O-methylation of 3-isobutyl-2-hydroxypyrazine (IBHP) and 3-isopropyl-2-hydroxypyrazine (IPHP) precursors, respectively, via an S-adenosyl-methionine dependant O-methyltransferase (Hashizume et al. 2001a, Hashizume et al. 2001b). Ryona et al. (2010) reported a strong inverse correlation between IBMP and IBHP in grapes (R^2 = 0.998) and bell peppers (R^2 = 0.958) over a wide range of maturities. A significant decline in IBMP with a concomitant increase in IBHP was observed over ripening suggesting that MP degradation occurs through demethylation to the initial hydroxypyrazine precursor.

Methoxypyrazines in Grapes and Wine

Of an estimated 15,000 named grape cultivars (*Vitis sp.*) (Jackson 2000), only some of the Bordeaux cultivars and several interspecific hybrids are reported to produce significant concentrations of MPs. In general, MP concentrations in mature fruit and wine range from 0 to 50 ng/L and the predominant form, IBMP, is typically present at concentrations an order of magnitude higher than IPMP or sBMP (Alberts et al. 2009). However, concentrations up to 161 ng/L were reported in some Carmenere wines (Belancic and Agosin 2007) and concentrations in excess of 200 pg/g were observed in immature, green berries (Ryona et al. 2008, Scheiner et al. 2010). In wines affected by Multicolored Asian Lady Beetle (*Harmonia axyridis*) taint, IPMP may be the predominant MP, present at relatively high concentrations (Pickering et al. 2005).

The sensory detection threshold of IBMP in red and white wine is variously reported as 8 to 16 ng/L (Allen and Lacey 1999, de Boubee et al. 2000, Kotseridis et al. 1998) and 1 to 2 ng/L (Allen et al. 1988, Allen et al. 1991), respectively, and the sensory detection threshold of IPMP is reported as 0.30 to 2 ng/L in white wine and 1 to 2 ng/L in red wine (Pickering et al. 2007). When present near the sensory detection threshold, MPs may enhance wine quality by adding complexity and in some cases, varietal character (Allen et al. 1991). At higher concentrations, IBMP positively correlates with bell pepper and other herbaceous aromas (Allen et al. 1991, de Boubee et al. 2000, Kotseridis et al. 1998, Pickering et al. 2005, Pickering et al. 2008). Although sBMP and IPMP are usually present at relatively low concentrations, it is hypothesized that MPs have an additive effect on wine herbacousness (Allen and Lacey 1999). Based on mutual suppression (Lawless 1986), the herbaceous aromas associated with MPs can mask the perception of fruity/ripe aromas (Campo et al. 2006, Hein et al. 2009, Pickering et al. 2004).

Distribution of Methoxypyrazines in Grapes

In a mature grape cluster, MP concentrations are highest in stems (>50%) followed by skin (> 40%), seeds, and pulp (Hashizume and Samuta 1997, de Boubee et al. 2002). Within a mature grape berry, a large majority of IBMP (> 95%) is located in the skins (de Boubee et al. 2002).

IBMP begins to accumulate in berries around set and peaks 0 to 2 weeks prior to veraison, followed by a rapid decline over the ripening period (de Boubee et al. 2002, Hashizume and Samuta 1999, Ryona et al. 2008, Sala et al. 2004, Scheiner et al.

2010). By fruit maturity, IBMP concentrations are generally < 10 % of their corresponding peak values (Ryona et al. 2008). Ryona et al. (2008) observed that peak IBMP concentrations (47 days after anthesis) strongly correlated ($R^2 = 0.936$) with concentrations at maturity suggesting that final IBMP concentrations are influenced by preveraison accumulation.

Factors Affecting Methoxypyrazine Concentrations in Grapes

Grape cultivar and clone. The *Vitis vinifera* cultivars known to produce significant concentrations of MPs are Cabernet Sauvignon, Cabernet franc, Merlot, Carmenere, Sauvignon blanc, and Semillon. Because few cultivars in the species produce high MP concentrations, synthesis is thought to be under genetic control (Allen and Lacey 1999). Various genotypes of Carmenere (Belancic and Agosin 2007), Merlot (Kotseridis et al. 1998), and Cabernet Sauvignon (Battistutta et al. 2000) have been evaluated for inherent MP production with > three-fold concentration differences observed between genotypes. However, the only study to evaluate genotypic variation over multiple seasons reported a greater degree of variability in IBMP across years (Kotseridis et al. 1998). Wild grape species, *Vitis riparia* and *Vitis cineria*, and several interspecific hybrids are also known to produce relatively high MP concentrations (Sun et al. 2010), but little research outside of the Bordeaux cultivars has been published.

Vintage and location. Virtually all multi-year and/or multi-location studies report year to year and/or location to location variability in MPs (Allen et al. 1991, Belancic and Agosin 2007, de Boubee et al. 2000, Falcao et al. 2007, Hashizume and

Umeda 1996, Kotseridis et al. 1998, Kotseridis et al. 1999b, Lacey et al. 1991, Marais 2004, Ryona et al. 2008, Scheiner et al. 2010). For example, Belancic and Agosin (2007) observed a two-fold difference in IBMP (15.7-30.5 pg/g) between Carmenere grapes grown in the same year in different vineyards in Chile and up to a six-fold difference (15.7-100.4 pg/g) across years for grapes grown in the same vineyards. In concurrence with several other reports (Allen et al. 1991, Kotseridis et al. 1998), the authors attribute variability across years and locations to the impact of prevailing environmental conditions on vine growth.

Recently, considerable (> two-fold) vine-to-vine variation in IBMP was reported in Cabernet franc berries grown in the same vineyard (Ryona et al. 2008). Although the author is unaware of any other accounts of vine-to-vine variability in MP concentration, intra-vineyard variability is well documented (Bramely 2005, Bramley and Hamilton 2004, Oke et al. 2007, Rankine et al. 1962). Profound differences in fruit and wine composition within a single vineyard can result from a variety of factors including heterogeneity in site characteristics, mesoclimate, cultural practices, and vine physiology. Because MPs are linked to both environmental and physiological factors, the occurrence of intra-vineyard variability is likely.

Light. Field and laboratory studies indicate that light plays a role MP metabolism (Allen and Lacey 1993, de Boubee et al. 2000, Hashizume and Samuta 1999, Heymann et al. 1986, Marais et al. 1999, Ryona et al. 2008, Sala et al. 2004). Several groups reported that cluster light exposure reduces MP concentrations in mature fruit. For example, Allen and Lacey (1993) compared IBMP concentrations in Cabernet Sauvignon grapes grown under varying levels of natural canopy shading, reported as leaf layer number (LLN), and fully exposed fruit (LLN = 0) had significantly less IBMP (~ 58%) than the most severely shaded fruit (LLN = 3) at both veraison and harvest. Similarly, Marais et al. (1999) and de Boubee (2003) reported that cluster exposure decreased final IBMP concentrations in Sauvignon blanc (~ 50%) and Cabernet Sauvignon (~ 68%), respectively. To determine if cluster exposure specifically impacts IBMP accumulation and/or degradation, Ryona et al. (2008) quantified IBMP in Cabernet franc berries growing in naturally shaded and exposed portions of vines at 10 time points from berry set to harvest. Significant reductions in IBMP accumulation (21 to 44%) during the pre-veraison period were observed in clusters growing in sun exposed portions of vines. However, cluster exposure did not influence the rate of postveraison degradation. Consequently, management practices that facilitate cluster exposure (e.g. leaf removal) do not affect final MP concentrations when imposed after veraison Scheiner et al. (2010).

Because sun exposed clusters can have elevated berry temperatures (Bergqvist et al. 2001, Smart, and Sinclair 1976, Spayd et al. 2002), some authors suggest that MPs are thermally degraded. A correlation between IBMP and malic acid was reported over the ripening period by several groups (de Boubee et al. 2000, Falcao et al. 2007, Lacey et al. 1991) and because malic acid is respired at a faster rate under higher temperatures (Lakso and Kliewer 1978), it is hypothesized that MP degradation may also be influenced by temperature. However, MPs stored in aqueous solutions are sensitive to photodecomposition (Heymann et al. 1986, Maga 1990), thus it is not clear if MPs are primarily influenced by light or temperature. Furthermore, it is unknown if cluster exposure reduces MP accumulation by decreasing synthesis and/or by increasing degradation.

Temperature. The relationship between growing season temperature and MPs is well documented (Allen et al. 1994, Belancic and Agosin 2007, Falcao et al. 2007, Hashizume and Umeda 1996, Kotseridis et al. 1998, Lacey et al. 1991, Marais 2004, Marais et al. 1999). In general, grapes and wines produced in cool climates and/or in cooler years have elevated MP concentrations. For example, Falcao et al. (2007) quantified IBMP in Cabernet Sauvignon wines produced in five regions of Brazil with distinct seasonal temperature patterns and observed that IBMP concentrations were strongly negatively correlated with average minimum and maximum growing season temperatures. A negative correlation between MPs and mean January temperature in was also reported by Allen et al. (1994). It is generally hypothesized that warmer ripening temperatures accelerate fruit maturation and MP degradation (Hashizume and Umeda 1996, Kotseridis et al. 1998, Lacey et al. 1991). However, the relative importance of temperature during the preveraison period has not been determined.

Vine Water Status. High vine water status is associated with high MPs (Belancic and Agosin 2007, de Boubee 2003, Sala et al. 2005), although the mechanism is unclear. de Boubee (2003) suggests that IBMP concentrations are dependent upon early season vine water status and excessive water availability acts as a stimulator of IBMP biosynthesis. According to this hypothesis, IBMP is synthesized in the leaves and translocated to fruit through conductive tissues. Thus, conditions that stimulate vigor such as high vine water status result in a greater source of IBMP. However, increased vine growth can lead to cluster shading, potentially confounding the light and vigor effect. In contrast, Sala et al. (2005) reported that the availability of free water over the ripening period results in higher MPs due to a delay in degradation.

Soil. Soil types that promote vine vigor through water retention are also associated with high MPs. de Boubee et al. (2000) reported higher IBMP concentrations at both veraison (~ 25%) and harvest (~100%) in Cabernet Sauvignon grapes grown on sandy-silt soils compared to grapes grown gravelly soils. A marked difference in MP degradation rate was also noted between the two soil types. Noble et al. (1995) observed a > thirteen-fold difference (2.8 to 37 ng/L) in IBMP in Cabernet Sauvignon wines produced on a variety of soil types. In general, soils with higher water holding capacities produced more vigorous vines with greater fruit shading and higher IBMP concentrations. Although the relative importance of specific soil properties (e.g. chemical composition) is unknown, soil fertility as it relates to vine vigor and cluster light exposure may influence MPs.

Canopy management. Although the specific environmental and/or physiological factor(s) that directly influence MPs are undetermined, the underlying relationship with cluster exposure and vine vigor can be manipulated through viticultural practices (Allen and Lacey 1993, Chapman 2004, Chapman et al. 2004, de Boubee 2003, Ryona et al. 2008, Sala et al. 2004 , Sala et al. 2005, Scheiner et al. 2010). Vine spacing and training systems that facilitate cluster light exposure and mitigate vine vigor are shown to reduce MPs (Sala et al. 2004, Sala et al. 2005). Canopy management practices such as fruit zone leaf and lateral removal can significantly decrease IBMP accumulation resulting in lower concentrations at fruit maturity (de Boubee 2003, Scheiner et al. 2010). Scheiner et al. (2010) observed reductions in final IBMP concentrations up to 88% in Cabernet Franc berries by removing leaves in the fruiting zone prior to veraison. However, postveraison leaf removal was ineffective.

Pruning strategies are linked to MPs through alterations in yield, vigor, and cluster exposure (Allen and Lacey 1993, Chapman 2004, Chapman et al. 2004, Ford 2007). Chapman et al. (2004) reported a significant negative correlation between the number of buds per vine left after winter pruning and IBMP content in resulting wines. The authors suggest that yield has a direct impact on IBMP. However, cluster thinning treatments, also imposed as a means of yield manipulation, had no effect (Chapman 2004). In contrast, Ford (2007) suggests that MPs are influenced by pruning through alterations in crop load (leaf area/fruit). In this study, Sauvignon blanc vines pruned to 4 canes (crop load ~ 10.45 cm^2/g) produced fruit with significantly less (~53.7 %) IBMP at harvest than vines pruned to 2 canes (crop load ~ 19.53cm^2/g). Although vigor, crop load, and canopy microclimate were not assessed by Chapman et al. (2004), the observed effects could have been a function of the aforementioned factors. Pruning strategies that leave more nodes, thus more shoot and fruit development, can reduce vigor, increase crop load, and improve cluster exposure. In concurrence, Allen and Lacey (1993) reported an eight-fold difference in MPs in minimally pruned vines versus spur pruned vines. Vines that were minimally pruned were less vigorous and more exposed clusters than the spur pruned vines resulting in lower MPs.

Grape maturity. The pattern of MP concentration over berry development indicates that adequate fruit maturation is critical to control MPs. Correlations between MPs and maturity indices total soluble solids (Hashizume and Umeda 1996) and malic acid (Chapman et al. 2004, de Boubee et al. 2000, Hashizume and Umeda 1996, Kotseridis et al. 1999b) have been reported. However, these relationships are not consistently observed, thus classic maturity indices do not serve as an accurate proxy for IBMP. In contrast, peak IBMP concentrations were reported to strongly correlate with IBMP concentrations in mature fruit suggesting that IBMP content is partially determined during the pre-veraison period (Ryona et al. 2008). However, little is known about the utility of extended hang beyond physiological maturity. Belancic and Agosin (2007) reported that IBMP plateaus before end of sugar accumulation, but the author is unaware of any other reports.

Vinification and Cellaring Practices to Control Methoxypyrazines

In a grape cluster, the majority of MPs are located in the stems and skins (de Boubee et al. 2002, Hashizume and Samuta 1997, Hashizume et al. 1998), thus enological practices such as pressing (de Boubee 2003, Kotseridis et al. 1999) destemming (Hashizume and Samuta 1997), and cap management (Marais 1998) have been evaluated as potential strategies to reduce MPs. Because high concentrations of MPs are present in rachises, proper destemming can exclude a potential source of MPs (Hashizume and Samuta 1997). However, extraction from skins is thought to be inevitable with conventional red wine making techniques. MPs are quantitatively extracted in < 72 hours of skin contact (de Boubee et al. 2002, Sala et al. 2002). Ryona et al. (2009) reported a strong correlation ($R^2 = 0.97$) between IBMP concentration in Cabernet franc grapes and their resulting wines suggesting that MP concentrations in red wine can be accurately predicted prior to fermentation.

Numerous techniques to remove MPs from musts and wine have been evaluated, but thus far, all remediation treatments were either ineffective or did not altered other, potentially desirable wine properties. Thermovinification removes MPs through volatilization (de Boubee 2003), but other aspects of wine composition and sensory perception are altered in the process (Francis et al. 1994, Girard et al. 1997).

Fining agents such as activated charcoal can effectively remove MPs from wine, but other wine constituents may be removed (Pickering et al. 2006). Blake et al. (2009) recently reported that certain closure and packaging types can remove MPs from wine, but the authors also noted significant decreases in other potential impact odorants. Practices such as oak contact (Howell et al. 2006, Pickering et al. 2006), bentonite fining (Pickering et al. 2006), pectinases (Howell et al. 2006), microoxygenation (Zoecklein 2008), hyperoxidation, and wine storage temperature (Marais 1998) have also been evaluated, but these treatments did not have a significant impact on MP concentrations. To date, there are no vinification and cellaring techniques to selectively remove MPs from musts or wine.

Research Objectives

MP levels in wine are largely dependent upon the concentration in grapes at harvest. Therefore, it is necessary to develop effective viticultural techniques to reduce MPs in fruit. Previous research provides valuable insight into potential control strategies; however the relative importance of specific viticultural factors is unknown. Climate and vine physiology play a role in MP evolution, but the factors previously identified may cross-correlate obscuring direct and indirect effects. The objectives of this research are to (i) conduct a multivariate study to evaluate the correlation between viticultural parameters (meso- and microclimate, and vine physiology) and IBMP concentrations in Cabernet franc grapes (ii) evaluate the impact of vineyard management practices: basal leaf removal, shoot tipping, plant growth retardants, and clonal selection on IBMP concentrations in Cabernet franc berries (iii) evaluate the correlation between IBMP concentration in Cabernet franc wines and intensity of herbaceous and fruity aromas.

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CHAPTER 2

IMPACT OF SEVERITY AND TIMING OF BASAL LEAF REMOVAL ON 3-ISOBUTYL-2-METHOXYPYRAZINE CONCENTRATIONS IN RED WINE GRAPES

Abstract

Field studies were conducted on *Vitis vinifera* L. cvs. Cabernet franc and Merlot to evaluate the effects of basal leaf removal timing and severity on 3-isobutyl-2-methoxypyrazine (IBMP) concentration in grape berries. Treatments consisted of removing either 50% or 100% of leaves from the fruiting zone at either anthesis, 10 days after anthesis, 40 days after anthesis, or 60 days after anthesis. In the second year of the Cabernet franc study, a 15-day post-veraison leaf removal treatment was also included. Significant reductions in IBMP (range = 28 to 53%) were observed prior to veraison compared to the control in both 10 days after anthesis treatments (50% and 100% leaf removal) in both years of the Cabernet franc study. In 2007, all leaf removal treatments significantly reduced IBMP concentrations compared to the control (range = 46 to 88%) in Cabernet franc berries at harvest, with the greatest reduction observed in the 100% leaf removal treatments at 10 days after anthesis and 40 days after anthesis. In 2008, the 100% leaf removal treatment at 10 days after anthesis and the 50 and 100% leaf removal treatments at 40 days after anthesis significantly reduced IBMP concentrations (range = 34 to 60%) in mature Cabernet franc berries. In the Merlot trial, all leaf removal treatments significantly reduced IBMP concentrations (range = 38 to 52%) at harvest. In summary, early season (10 to 40 day after-anthesis) basal leaf removal reduced IBMP accumulation pre-veraison compared to the control in both studies, suggesting that leaf removal at that time is a

more effective management strategy to reduce IBMP accumulation in grape berries than leaf removal later in the season.

Introduction

The 3-alkyl-2-methoxypyrazines (MPs) are a class of odorants associated with "green", herbaceous aromas of some Bordeaux wine grape (*Vitis vinifera* L.) cultivars. Quantitatively, 3-isobutyl-2-methoxypyrazine (IBMP) is the predominant MP in grapes and wine, typically an order of magnitude higher in concentration than 3-isopropyl-2-methoxypyrazine (IPMP) and 3-*sec*-butyl-2-methoxypyrazine (sBMP) (Alberts et al. 2009). The sensory detection threshold for IBMP is reported to range from 0.5 to 2 pg/g in water (Buttery et al. 1969, Kotseridis et al. 1998, Seifert et al. 1970) and 10 to 15 pg/g in red wine (de Boubee et al. 2000, Kotseridis et al. 1998). When present at concentrations near sensory threshold, MPs may contribute positively to wine quality by adding complexity and in some cases, varietal character (Allen et al. 1991). At higher concentrations, MPs can result in excessive herbaceousness and suppressed fruitiness in wines (Allen and Lacey 1999, Hein et al. 2009, Pickering et al. 2005). MPs are efficiently extracted by conventional red wine practices, and their concentrations in wine are strongly correlated to their concentrations in grapes (Ryona et al. 2009). Several studies have evaluated the efficacy of vinification and cellaring practices in reducing MPs (Blake et al. 2009, de Boubee 2003, Marais 1998, Pickering et al. 2006), and have generally concluded that remediation of MPs is ineffective or else results in other non-selective changes to the wine. Viticultural management strategies that reduce MPs in the vineyard have thus been proposed to be the most effective way to control MP concentration in wine (Bogart and Bisson 2006).

In grape berries, IBMP begins to accumulate around 10 days after anthesis with a peak in concentration occurring approximately 0 to 14 days prior to veraison, followed by a rapid decline during maturation (de Boubee et al. 2000, Hashizume and

Samuta 1999, Ryona et al. 2008, Sala et al. 2004). IBMP concentrations in mature berries are reported to be less than 10% of their pre-veraison peak concentrations. Ryona et al. (2008) reported a strong correlation (R^2 = 0.936) between IBMP concentrations in mature Cabernet franc berries and pre-veraison peak concentrations suggesting that final IBMP concentration is primarily determined pre-veraison. Thus, management practices that affect initial accumulation of MPs in grapes pre-veraison are expected to more dramatically impact final MP concentrations at harvest than interventions later in the season.

Fruit zone leaf removal is a widely utilized viticultural practice, and has been demonstrated to yield improved fruit chemistry at harvest (Percival et al. 1994, Poni et al. 2006, Reynolds et al. 1994, Zoecklein et al. 1992, Zoecklein et al. 1998) as well as improved fungal control (Chellemi and Marois 1992, Percival et al. 1994, Wolf et al. 1986, Zoecklein et al. 1992). These effects are generally hypothesized to be mediated through an increase of sunlight reaching the fruiting zone. Several groups have observed that cluster light exposure results in lower MP concentrations in mature fruit (Allen et al. 1996, de Boubee et al. 2002, de Boubee 2003, Marais et al. 1999, Noble et al. 1995, Ryona et al. 2008). Recent work suggests that sun-exposed clusters accumulate less IBMP pre-veraison than shaded clusters within the same vine (Ryona et al. 2008) and that the proportional differences persist until harvest, although the physiological mechanisms behind these effects are not understood. Most of the aforementioned studies have observed differences between shaded and exposed fruit by using artificial shading or taking advantage of natural variation in light exposure within the canopy, but little work has been published on the effectiveness of specific vineyard practices (e.g. leaf removal) to reduce MP accumulation pre-veraison and subsequent levels at harvest. Roujou de Boubee (2003) observed a 68% reduction in

IBMP concentration of Cabernet Sauvignon at harvest resulting from removal of lateral shoots and basal leaves on the east side of the fruiting zone at fruit set compared to an unthinned control. A similar treatment imposed post-veraison resulted in only a 10% reduction in IBMP at harvest. However, this report did not consider more than one pre-veraison leaf removal timing, the period when the accumulation of MPs is greatest (Ryona et al. 2008), nor did it investigate the effects of the severity of leaf removal. We are unaware of any other literature that has quantified the impact of leaf removal on MPs in grape berries. The objective of this study was to investigate the impact of timing and severity of leaf removal on IBMP concentration in Cabernet franc in the Finger Lakes, and Merlot on Long Island, NY.

Materials and Methods

Experimental design. Two commercial vineyards located in Ovid, New York (42.67ºN, 76.82ºW; Finger Lakes American Viticultural Area, Cayuga Lake) and Cutchogue, New York (40.99ºN, 72.48ºW; Long Island American Viticultural Area, North Fork) were used in this study. The soil types were classified by the USDA as Howard series with a gravelly loam structure, well drained, and a depth of > 2 meters and Haven series with a loamy structure, well drained, and > 2 meters deep at the Finger Lakes and Long Island sites, respectively. Vines at the Finger Lakes site were *Vitis vinifera* L. cv. Cabernet franc cl. 1 grafted on 3309C rootstock trained to a Scott Henry system with four canes. The upper canes were at 1.3 meter height and shoots vertically positioned. The lower canes were at 1.0 meter height and shoots were positioned downward. The vines at the Long Island site were Merlot cl. 181 grafted on 3309C rootstock trained to a combination of low wire cordon and a flat cane system with either two cordons or two canes at 1.0 meter height and shoots vertically positioned. Vine spacing was 2.0 meters between vines and 2.5 meters between rows for both sites. Vine management was performed according to the standard viticultural practices for *vinifera* in the Finger Lakes and Long Island regions. The experimental design was a randomized complete block with four replications. The experimental plot at each site consisted of four rows and each experimental unit consisted of eight contiguous vines in each row.

Treatments consisted of a control (no leaf removal), removing the first, third, and fifth leaf from the base of each shoot at 10 days after anthesis (10 DAA 50%), forty days after anthesis (40 DAA 50%), or sixty days after anthesis (60 DAA 50%); and removing the first five leaves beginning at the base of each shoot at 10 days after anthesis (10DAA 100%), forty days after anthesis (40 DAA 100%), or sixty days after anthesis (60 DAA 100%). Two additional treatments were added at the Cabernet franc site in the second year of the study: removing the first, third, and fifth leaf from the base of each shoot at fifteen days after veraison (15 DAV 50%) or removing the first five leaves from the base of each shoot at fifteen days after veraison (15 DAV 100%). All basal leaf removal treatments were applied by hand on all fruiting and non-fruiting shoots of each vine. The beginning of bloom was noted on 18 June 2007 and19 June 2008 (Cabernet Franc), and 22 June 2008 (Merlot), respectively. Time of anthesis was determined as the date on which 50% capfall was visually estimated. In 2007, the calendar dates for the treatments in Cabernet franc were anthesis (17 June), 40 days after anthesis (27 July), 60 days after anthesis (16 August), and harvest (21 October). In 2008, the calendar dates for the treatments in Cabernet franc and Merlot were anthesis (18 June and 21 June, respectively), 40 days after anthesis (28 July and 31 July), 60 days after anthesis (17 August and 20 August), and harvest (20 October and

16 October). The 15 day post-veraison treatment was performed on Cabernet franc on 6 September 2008.

Sampling and harvest. Five days after each basal leaf removal treatment was imposed in 2007 (15, 45, and 65 days after anthesis) and five to fifteen days after each basal leaf removal treatment was imposed in 2008 (15, 50, 75, 85 days after anthesis) in Cabernet franc, 50-berry samples were collected at random from each experimental unit for IBMP quantification. At harvest, 150 berries were collected at random from each experimental unit in Cabernet Franc and Merlot for IBMP quantification and chemical analysis. The berry samples were placed in plastic storage bags and immediately frozen followed by storage at -23ºC for later analysis.

Yield components were assessed in the 2008 Cabernet franc and Merlot studies. At harvest, yield (measured with a hanging scale accurate to 0.01 kg; model SA3N340, Salter Brecknell, Fairmont, MN) and cluster counts were determined for each vine and an average was recorded for each replication. Crop weight and number of clusters were used to calculate average cluster weight. Yield data was not recorded in the 2007 Cabernet franc study due to a significant “green harvest” of fruit by the grower several weeks before harvest. In the 2008 Cabernet franc study, cluster thinning at veraison was employed by the grower in all treatments to eliminate the least mature clusters.

Berry analysis for ºBrix, titratable acidity, and pH. A sub-sample of 100 mature berries per experimental unit was removed from the -23ºC freezer, placed in a 250-mL beaker and heated to 65 ºC for one hour in a water bath to redissolve tartrates, pressed through cheesecloth with a pestle, and the juice was collected for analyses. Soluble solids (ºBrix) were measured using a digital refractometer (model 300017;

SPER Scientific, Scottsdale, AZ) with temperature correction. TA and pH were measured with an automatic titrater (Titrino model 798, Metrohm, Riverview, FL). TA was measured with a 5.0-mL aliquot of juice by titration against 0.1 N NaOH to pH 8.2.

Berry analysis for 3-isobutyl-2-methoxypyrazine. IBMP analysis was conducted using 50-berry samples. The extraction method was head space-solid phase micro extraction (HS-SPME) and quantification was performed by comprehensive two-dimensional gas chromatography time-of-flight mass spectrometry (GCxGC-TOF_MS) as described elsewhere (Ryona et al. 2009). In brief, HS-SPME was conducted using a LEAP CombiPAL Autosampler (Carrboro, NC. USA) fitted with a three-phase fiber (DVB/CAR/PDMS). A 10 min online incubation at 650 rpm agitation rate and an incubation temperature of 80°C was applied prior to headspace-fiber insertion and equilibrium. Following fiber insertion, the vial was agitated at 100 rpm for 30 min at 80°C. Quantification was performed by GCxGC-TOF-MS (Pegasus IV, Leco Corp, St. Joseph, MI. USA). SPME injections were splitless with a desorption temperature of 270 °C. The first capillary column (30m × 0.25 mm × 0.50 μm) was an RTX5 (Restek, Bellefonte, PA), and the second column (2.5m × 0.10 mm × 0.10 μm) was a VF-WAXms (Varian, Palo Alto, CA). Helium was used as a carrier gas at a flow rate of 1 mL/min. The temperature program was as follows: initial hold for 5 min at 40 °C, followed by a 5 °C/min ramp to 120 °C; then, 2 °C/min to 150 °C, no hold; then 10 °C/min to 250 °C, 15 min hold. The GC×GC modulation time was 3 s. The MS transfer line temperature was 230 °C. The TOF-MS was operated in EI mode with an ionization energy of 70 eV. The electron multiplier was set to 1680 V. The TOF-MS data were stored at an effective acquisition rate of 120 Hz over a mass range of m/z 20-400. The qualifier ions were m/z=124, 151, 166 for IBMP and *m/z*=126, 153, 168 for [$^2H_2$]-IBMP. The quantifier ions were *m/z*=124 and 126, respectively.

Statistical analysis. Statistical analyses were conducted with SAS® statistical software (SAS Institute, Cary, North Carolina). Data was subjected to the Proc GLM procedure and means were separated using the Fischer's protected least significant difference (LSD) at the 5% significance level. IBMP data for harvested Cabernet franc berries in 2007 and 2008 were not combined over years due to significant year by treatment interaction.

Results

Leaf removal in Cabernet franc. Leaf removal timing and severity impacted the concentration of IBMP pre-veraison and at harvest in both 2007 and 2008. In 2007, at 15 days after anthesis, IBMP was present at quantifiable concentrations (data not shown), but no significant difference was observed in IBMP between the 10 DAA leaf removal treatment and the untreated vines. At 45 days after anthesis, both the 10 DAA 50% and 10 DAA 100% treatments significantly reduced IBMP concentrations by 52 and 53%, respectively, compared to the control (Figure 1A). At 65 days after anthesis, the concentrations of IBMP in the 10 DAA 50% and 10 DAA 100% treatments were 55 and 65%, respectively, lower than the control (Figure 1B). The period between veraison (65 days after anthesis) and harvest (125 days after anthesis) was marked by a decline in IBMP concentration. The IBMP concentration in mature fruit ranged from 0.5 to 4.3 pg/g (Figure 1C) and averaged 1.1% of the observed maxima (65 days after anthesis). Although the only significant reduction in IBMP concentration at the three pre-harvest sample timings was observed for the 10 DAA 50%, 10 DAA 100%, and

40 DAA 100% treatments, all leaf removal treatments significantly reduced IBMP in mature berries with respect to the control (Figure 1C). The range in ºBrix of the Cabernet franc berries at harvest in 2007 was 19.4 to 22.3 (Table 1). The 10 DAA 50% and 10 DAA 100% treatments significantly increased ºBrix compared to the control by 5 and 10%, respectively. TA ranged from 6.4 to 8.6 g/L across treatments. All leaf removal treatments except the 60 DAA 50% treatment significantly reduced TA compared to the control.

In 2008, the 10 DAA 50% and 10 DAA 100% treatments significantly reduced the concentration of IBMP in Cabernet franc berries at 50 days after anthesis by 28% and 36% (Figure 1D). At 75 days after anthesis the 10 DAA 100% and 40 DAA 100% treatments reduced IBMP concentrations by 25% and 48%, respectively (Figure 1E). At 85 days after anthesis, there were no significant differences among treatments (data not shown). At harvest (124 days after anthesis), the range in IBMP concentration across all treatments was 1.2 to 3.5 pg/g (Figure 1F) and averaged 1.3% of the observed pre-veraison (50 days after anthesis) maxima. Although the 10 DAA 50% and 100% treatments significantly reduced IBMP concentrations at the pre-veraison sample timing, the 10 DAA 100%, 40 DAA 50%, and 40 DAA BS 100%

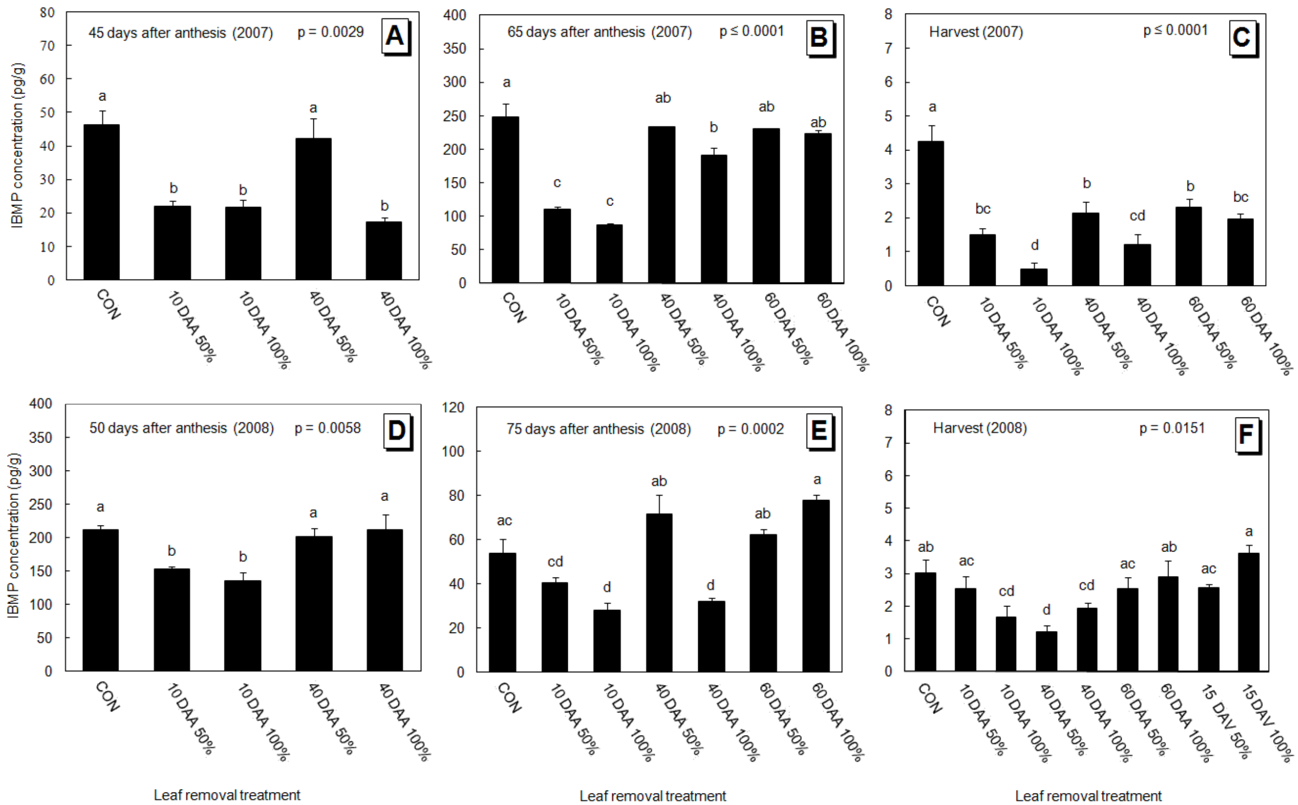

Figure 1 Impact of basal leaf removal severity and timing on IBMP concentration in Finger Lakes Cabernet franc berries at **(A)** 45 days after anthesis, 2007; **(B)** 65 days after anthesis, 2007; **(C)** harvest, 2007**; (D)** 50 days after anthesis, 2008; **(E)** 75 days after anthesis, 2008; **(F)** harvest, 2008. Each measurement represents the average of four field replicates. Values are mean ± standard error. Means indicated by different letters are significantly different at $p \leq 0.05$, Fisher's Least Significant Difference.

Table 1 Brix, titratable acidity (TA), and pH of Cabernet franc and Merlot in response to basal leaf removal treatments, 2007-2008.

Leaf removal treatment	ºBrix	Titratable Acidity (g/L)	pH
2007 Cabernet franc			
10 DAA 50%	21.1ab[b]	7.0cd[c]	-
10 DAA 100%	22.3a	6.4d	-
40 DAA 50%	20.5bc	7.6bc	-
40 DAA 100%	19.4c	7.3bd	-
60 DAA 50%	19.8c	8.0ab	-
60 DAA 100%	20.0bc	7.3bc	-
CON	20.1bc	8.6a	-
Significance[a]	*	*	-
2008 Cabernet franc			
10 DAA 50%	22.0	6.4ab	3.63
10 DAA 100%	21.9	5.8cd	3.64
40 DAA 50%	21.7	5.7cd	3.65
40 DAA 100%	21.9	5.8cd	3.61
60 DAA 50%	21.4	6.1bc	3.66
60 DAA 100%	22.5	5.5d	3.65
15 DAV 50%	22.3	6.1bc	3.63
15 DAV 100%	22.0	5.7cd	3.65
CON	21.1	6.8a	3.71
Significance	ns	*	ns
2008 Merlot			
10 DAA 50%	20.4	6.3	3.61
10 DAA 100%	20.4	5.9	3.66
40 DAA 50%	20.2	6.2	3.60
40 DAA 100%	20.8	6.0	3.63
60 DAA 50%	20.5	6.6	3.59
60 DAA 100%	21.0	6.2	3.63
CON	19.9	6.8	3.56
Significance	ns	ns	ns

[a]ns and * indicate not significant at the 0.05 probability level and statistically significant at the 0.01 probability level, respectively.
[b]Means followed by different letters are significant at $p \leq 0.01$ (Fisher's LSD).
[c]Not presented because of inconsistent data.

leaf removal treatments significantly reduced IBMP concentrations (range = 34 to 60%) at harvest. The range in ºBrix was 21.1 to 22.5 with no significant differences among treatments (Table 1). TA ranged from 5.5 to 6.8 g/L among treatments. All treatments except 10 DAA 50% significantly reduced TA below the control. No differences in juice pH were observed among the leaf removal treatments. Yield, number of clusters, and average cluster weight per vine in 2008 ranged from 3.4 to 4.1 kg, 21.6 to 26.1, and 145.7 to 181.8 g respectively, with no significant differences among treatments (data not shown).

Leaf removal in Merlot. At harvest (117 days after anthesis), the range in IBMP concentration in Merlot berries across treatments was 3.2 to 6.7 pg/g (Figure 2). Leaf removal at all timings and severities significantly reduced IBMP by a range of 37 to 52% compared to the control. Leaf removal timing and severity had no significant impact on ºBrix, TA, and pH (Table 1). The 10 DAA 50% treatment had significantly lower yield (1.9 kg/vine) than the control and other treatments (range = 2.1 to 2.4 kg/vine). No significant differences were observed among treatments for number of clusters per vine (range = 12.8 to 14.8) and average cluster weight (range = 143.2 to 172.9 g).

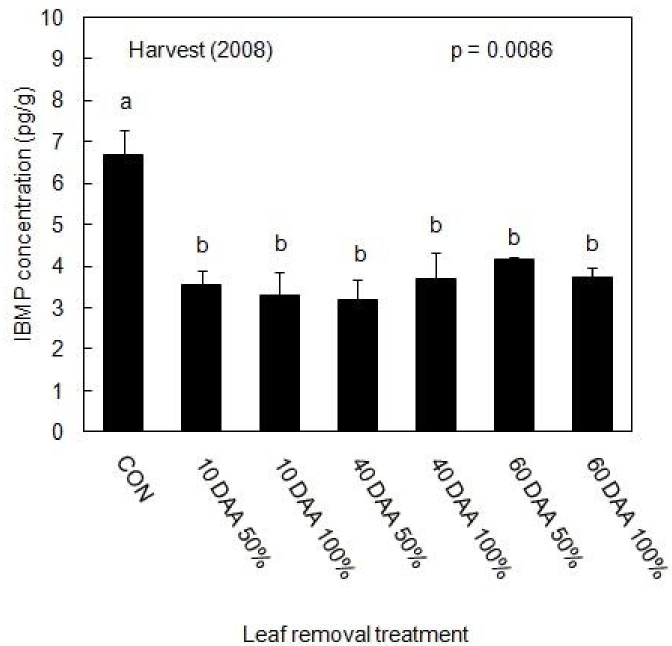

Figure 2 Impact of basal leaf removal severity and timing on IBMP concentration in Long Island Merlot berries at harvest, 2008. Each measurement represents the average of four field replicates. Values are mean ± standard error. Means indicated by different letters are significantly different at $p \leq 0.05$, Fischer's Least Significant Difference.

Discussion

The highest concentrations of IBMP in Cabernet Franc were observed at the pre-veraison sample timings (65 days after anthesis sampling in 2007, and at the 50 days after anthesis sampling in 2008 (Figure 1). Differences in reported peaks between years are likely a function of different sample timings. In agreement with our results, previous research has demonstrated that IBMP reaches a maximum in the 2 to 3 weeks prior to veraison (de Boubee et al. 2000, Lacey et al. 1991, Ryona et al. 2008).

In both 2007 and 2008, significantly lower IBMP concentrations were observed in Cabernet franc berries in the 10 DAA 50% and 10 DAA 100% treatments compared to the control at the time points just prior to or just after veraison (65 days post-anthesis in 2007, 50 days post-anthesis in 2008). No significant effect of leaf removal was observed at these points with the 40 DAA 50% or the two 60 DAA treatments in either year, although the 40DAA 100% treatment had lower IBMP than the control in 2007. These results are in concordance with a recent observation that cluster light exposure pre-veraison reduces IBMP accumulation (Ryona et al. 2008). Because basal leaf removal is widely shown to improve light penetration to the fruiting zone (Reynolds et al. 1996, Reynolds et al. 2006, Wolf et al. 1986, Zoecklein et al. 1992), the reductions in IBMP concentration that we observed are likely due to increased cluster light exposure. Generally, we did not observe a significant decrease in IBMP at the time point immediately following the treatment application. We did not observe significantly lower IBMP in the 40DAA 50% treatment at 45 days after anthesis in 2007 or at 50 days after anthesis in 2008, nor did we observe a significant effect for the 40 DAA 100% treatment at 50 days after anthesis in 2008. We did, however, observe significantly lower IBMP in the 40 DAA 100% treatment at 75 days after anthesis in 2008, and at 65 days after anthesis in 2007. Similarly, no significant difference in IBMP was observed between the 10 DAA treatments and the control at 15 days after anthesis in both years, nor was a difference observed at 75 days after anthesis between the 60 DAA treatments and the control. Thus, except for one case (40 DAA 100% in 2007), the impact of the leaf removal treatment was not observable until >15 days after the treatment was imposed.

Across all three studies, the largest and most consistent decreases for IBMP at harvest were observed in the early leaf removal treatments. In the 2007 Cabernet franc study, all treatments had significantly lower IBMP than the control at harvest, with the greatest reduction occurring in the 10 DAA 100% and 40 DAA 100% treatments (Figure 1C). In the 2008 Cabernet franc study, the 10 DAA 100%, 40 DAA 50%, and 40 DAA 100% treatments contained significantly lower IBMP at harvest compared to the control (Figure 1F). In the 2008 Merlot study, all treatments resulted in lower IBMP than the control at harvest (Figure 2). These results support the previous hypothesis that cluster light exposure pre-veraison inhibits accumulation pre-veraison, but has little effect post-veraison, and that the relative differences in IBMP established prior to fruit maturation persist until harvest (Ryona et al. 2008).

Although pre-veraison leaf removal (10 or 40 days post-anthesis) resulted in the largest decrease in IBMP levels at harvest compared to the control in the Cabernet franc studies, we also observed a smaller but still significant decrease in IBMP for the 60 DAA treatments in both the 2007 Cabernet franc and 2008 Merlot studies. Previous work (Allen et al. 1996, Marais et al. 1999, Ryona et al. 2008) indicates that cluster exposure reduces IBMP accumulation pre-veraison, but does not increase IBMP degradation during ripening on a percentage basis. A potential explanation is that IBMP synthesis and degradation are occurring simultaneously, at similar rates, in berries 40 to 60 days post anthesis. Thus, IBMP synthesis may still be occurring around veraison although the berry IBMP concentration is unchanged. In support of this hypothesis, we observed a sizeable decrease (41%) in 2008 Cabernet franc for the 40 DAA 100% treatment at Day 75 compared to the control, even though no significant decrease was observed at Day 50. However, IBMP synthesis likely does not persist late into the season. In the 15-day post-veraison treatments (50% and 100%) in the 2008 Cabernet franc study we observed no significant change in IBMP levels at harvest compared to the control (Figure 1F). Similarly, post-veraison cluster shading has been reported to have no impact on IBMP in Cabernet Sauvignon (Sala et al. 2004).

Several studies have reported that growing season temperature and MP content in mature berries are inversely correlated (Allen et al. 1991, Allen et al. 1994, Falcao et al. 2007). The total growing degree days (GDD, base 10^{o}C) accumulated at the Finger Lakes site 2007 and 2008 from January 1 to harvest (October 17 and 16) was 1552 and 1410, respectively (Figure 3). Although there were 142 more total GDD accumulated in 2007, there was less than 1% difference between years in GDD accumulated from 10 days after anthesis to veraison. The period between veraison and harvest was much warmer in 2007 (492 GDD during ripening) than in 2008 (349 GDD). Thus far, the relative importance of pre-veraison versus post-veraison growing season temperature in determining IBMP content in grapes has not been reported. Although we observed large differences in GDD between years, the average IBMP concentrations measured at harvest in Cabernet franc (2.0 pg/g in 2007 and 2.3 pg/g in 2008) were similar suggesting that the post-veraison GDD accumulation did not have a strong influence on final IBMP concentration. Ryona et al. (2008) noted a strong correlation between IBMP concentrations at veraison and harvest suggesting that final concentration is dependent upon pre-veraison conditions.

Although the harvest concentrations of IBMP observed in this study are below reported sensory thresholds in red wine (de Boubee et al. 2000, Kotseridis et al. 1998), the leaf removal treatments in 2007 and 2008 reduced the final IBMP concentration in Cabernet franc by up to 88% and 60%, respectively, and in Merlot by up to 52% compared to the control. In Cabernet franc, IBMP accumulation was reduced by up to 65% (2007) and up to 36% (2008) by the 10 DAA 50% and 10 DAA 100% treatments at the observed maximum IBMP concentrations. Our findings are consistent with other groups that have evaluated the effects of pre-veraison cluster light exposure on IBMP concentration (Allen et al. 1996, de Boubee 2003, Marais et al. 1999, Ryona et al. 2008).

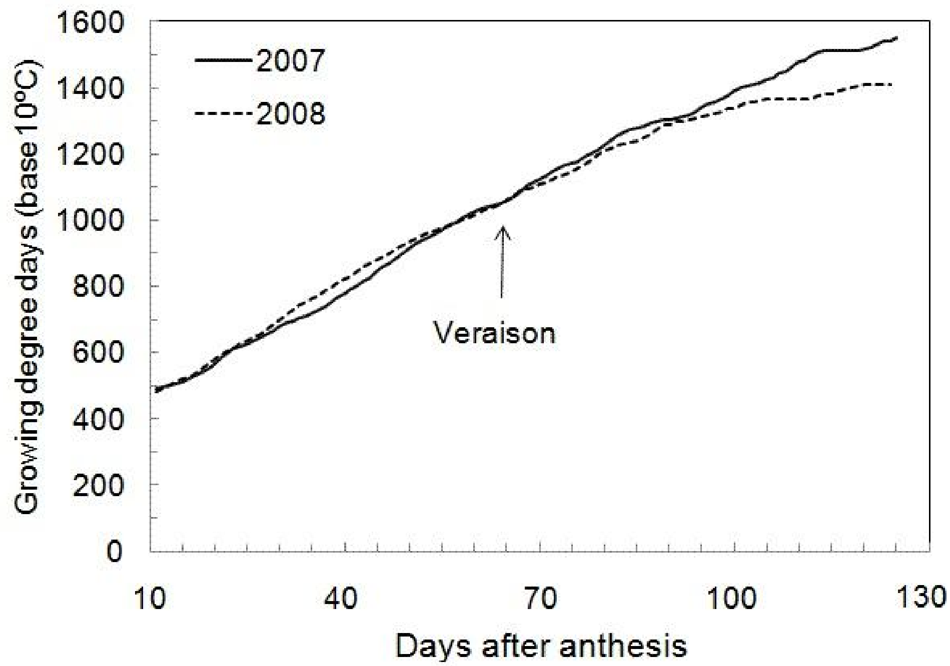

Figure 3 Growing degree days from 10 days after anthesis to harvest at Finger Lakes site in 2007 and 2008.

Conclusion

Pre-veraison basal leaf removal treatments reduced IBMP concentration in Cabernet franc and Merlot berries at harvest. In Cabernet franc, accumulation of IBMP in the pre-veraison period was reduced by leaf removal, likely due to improved light interception by the clusters. In a situation where IBMP is present in concentrations near detection, leaf removal during the growing season could be critical in reducing accumulation of IBMP. The earliest (10 days after anthesis and 40 days after anthesis) leaf removal treatments yielded the greatest benefit in reducing IBMP.

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CHAPTER 3

MULTIVARIATE ANAYLSIS OF VITICULTURAL IMPACTS ON 3-ISOBUTYL-2-METHOXYPYRAZINE CONCENTRATIONS IN CABERNET FRANC GRAPES

Abstract:

A multivariate study was conducted to determine the major environmental and viticultural factors that impact the concentration of 3-isobutyl-2-methoxypyrazine (IBMP) in Cabernet franc grapes. Vine measurements and fruit samples were taken from individual vines from two, five-vine panels per vineyard at ten and eight commercial Cabernet franc vineyards in 2008 and 2009, respectively. Temperature, rainfall, and photosynthetically active radiation were monitored over the growing season at each site. IBMP was quantified in grapes at 30 days after anthesis (DAA), 50 DAA, and harvest. In both years, significant differences were observed across sites for IBMP concentrations at all phenological stages (30 DAA, 50 DAA, and harvest). In the warmer growing season (2008), IBMP concentrations at 50 DAA were significantly higher than in 2009 (range 2008 = 103 to 239 pg/g; range 2009 = 12 to 87 pg/g) at all eight sites. Decrease in IBMP from 50 DAA to harvest was less in the cooler growing season (2009), but harvest concentrations (range 2008 = 1 to 13 pg/g; range 2009 5 to 14 pg/g) were not significantly different between years at five out of eight sites as a result of lower pre-veraison IBMP accumulation in 2009. Partial least squares regression (PLSR) was used to model the concentration of IBMP at 50 DAA and log-fold decrease in IBMP concentration from 50 DAA to harvest as a function of viticultural, and environmental data (122 variables in 2008; 140 variables in 2009).

The most important predictors for modeling IBMP concentration at 50 DAA were factors associated with vine vigor, and higher vigor was positively correlated with IBMP accumulation. Decrease in IBMP from 50 DAA to harvest could not be satisfactorily modeled across multiple sites, but within sites, factors associated with vine vigor, crop to vine size, and fruit maturity were important predictors. IBMP concentration in Cabernet franc wines did not correlate with intensity of herbaceous aroma likely because the highest concentration of IBMP in the wines under study was around the sensory detection threshold.

Introduction

The 3-alkyl-2-methoxypyrazines (MPs) are a class of odorants associated with herbaceous aromas of some Bordeaux wine grape (*Vitis vinifera* L.) cultivars (e.g. Cabernet franc, Merlot, Cabernet Sauvignon, Carmenere, Sauvignon blanc). In grapes and wine, three MPs are routinely reported: 3-isobutyl-2-methoxypyrazine (IBMP), 3-isopropyl-2-methoxypyrazine (IPMP), and 3-*sec*-butyl-2-methoxypyrazine (sBMP). Quantitatively, IBMP is predominant form, typically present in concentrations an order of magnitude higher than IPMP and sBMP (Alberts et al. 2009).

In red wine, the sensory detection threshold of IBMP is reported as 10 to 15 pg/mL (de Boubee et al. 2000, Kotseridis et al. 1998, Maga 1990). IBMP masks fruity aromas (Hein et al. 2009) and the positive correlation of IBMP with bell pepper aroma intensity is widely reported (Allen et al. 1991, de Boubee et al. 2000), although the relationship is less clear for concentrations around threshold (Preston et al. 2008), Because the herbaceous aromas associated with MPs are generally undesirable in red wine, there has been interest in developing management strategies to control MP levels. In mature grape berries, nearly all (> 95%) of IBMP is located in the skins (de Boubee et al. 2002) and is ~70% extracted with conventional red wine making practices (Ryona et al. 2009). Thus, the concentration in finished red wine is largely dependent on the concentration in grapes at harvest. Since current remediation techniques to remove MPs from musts or wine are either ineffective or else result in other nonselective changes (Blake et al. 2009, de Boubee 2003, Pickering et al. 2006), MPs are most effectively controlled with viticultural practices that reduce MPs in grapes (Bogart and Bisson 2006).

IBMP accumulates from fruit set until approximately 0 to 14 days prior to veraison (de Boubee et al. 2000, Hashizume and Samuta 1999, Ryona et al. 2008, Sala et al. 2004). During fruit maturation, MPs rapidly degrade to concentrations < 10% of their preveraison peak values. Preveraison IBMP concentrations correlate strongly to IBMP concentrations at harvest within the same growing region (Ryona et al. 2008).

In general, grapes and wines produced in cool regions and in cooler years are reported to have higher MP concentrations (Allen et al. 1994, Belancic and Agosin 2007, Falcao et al. 2007, Lacey et al. 1991, Kotseridis et al. 1998). Higher temperatures during the ripening period are thought to enhance MP degradation (Lacey et al. 1991) leading to lower concentrations at harvest.

Several groups have reported that cluster light exposure can reduce MPs at harvest (Allen et al. 1996, de Boubee et al. 2002, Maris et al. 1999, Noble et al. 1995, Ryona et al. 2008). Exposed clusters accumulate less IBMP than shaded clusters, and proportional differences persist until harvest. In contrast, cluster exposure does not influence the rate of postveraison degradation (Ryona et al. 2008). Consequently, management practices that improve cluster exposure (e.g. leaf removal) can reduce IBMP when imposed pre-veraison, but post-veraison treatments are ineffective (Scheiner et al. 2010).

Conditions that stimulate vine vigor such as high water availability and low bud numbers are associated with high MPs (Bogart and Bisson 2006, Belancic and Agosin 2007, Chapman et al. 2004, de Boubee 2003, Noble et al. 1995, Sala et al. 2005), although the mechanism is unclear. Higher preveraison IBMP concentrations have been observed at more vigorous sites (Noble et al. 1995) and vine growth during the ripening period, induced by high rainfall, was reported to result in higher IBMP concentrations over the ripening period (de Boubee et al. 2000). Ryona et al. (2008) observed higher concentrations of IBMP in vigorous vines with similar cluster exposures to vines of lower vigor suggesting that vine vigor and cluster light exposure may independently influence MPs.

In summary, cluster light exposure, temperature, fruit maturity, and conditions associated with vine vigor are linked to MPs, but it is unclear if the observed effects occur independently or indirectly. Many studies only quantified MPs in fruit at harvest or in wine so it is not possible to determine if differences noted were a function of MP accumulation and/or degradation. The objective of this study was to conduct a multivariate analysis to evaluate the correlation among viticultural factors, vine physiology and meso- and microclimate, and IBMP concentrations in Cabernet franc grape berries at pre-veraison and at harvest.

Materials and Methods

Experimental design. Ten and eight commercial Cabernet franc vineyards in New York State were utilized for this study in 2008 and 2009, respectively (Table 1). At each site, two, five-vine panels were selected as ‘experimental plots’ and experimental units consisted of single vines. Experimental plot selection was based on visual uniformity across each five-vine panel. All measurements and sampling were performed on individual experimental units. Vine management was performed according to the standard viticultural practices for *vinifera* in the respective region.

Vine/canopy characterization. The number of count and non-count shoots was recorded at anthesis and 50 days after anthesis (50 DAA), and shoot density was

Table 1 Location of vineyards (sites) and characteristics for 5-vine panels used in the multivariate study.

Site	Panel	American Viticultural Area	Clone	Rootstock	Spacing[a]	Training system	Vineyard age[c]	Soil Series[d]
1	1	Finger Lakes	unknown	3309C	2.7 x 1.6	two-tier flatbow vsp[b]	7	Aurora
1	2	Finger Lakes	unknown	3309C	2.7 x 1.6	two-tier flatbow vsp	7	Aurora
2	1	Finger Lakes, Seneca Lake	1	3309C	2.7 x 1.8	two-tier flatbow vsp	13	Cayuga
2	2	Finger Lakes, Seneca Lake	1	3309C	2.7 x 1.8	two-tier flatbow vsp	11	Honeoye
3	1	Finger Lakes, Seneca Lake	1	SO4	2.7 x 1.7	two-tier flatbow vsp	unknown, >15	Cayuga
3	2	Finger Lakes, Seneca Lake	1	SO4	2.7 x 1.7	two-tier flatbow vsp	unknown, > 15	Cayuga
4	1	Finger Lakes, Seneca Lake	1	SO4	3.0 x 2.2	cordon spur/flat cane Scott Henry vsp	6	Howard
4	2	Finger Lakes, Seneca Lake	1	SO4	3.0 x 2.2	cordon spur/flat cane Scott Henry vsp	6	Howard
5	1	Finger Lakes, Seneca Lake	214	SO4	3.0 x 2.2	cordon spur/flat cane Scott Henry vsp	9	Howard
5	2	Finger Lakes, Seneca Lake	214	SO4	3.0 x 2.2	cordon spur/flat cane Scott Henry vsp	9	Howard
6	1	Finger Lakes, Seneca Lake	unknown	3309C	2.7 x 1.7	cordon spur Scott Henry vsp	22	Honeoye
6	2	Finger Lakes, Seneca Lake	unknown	3309C	2.7 x 1.7	cordon spur vsp	15	Aurora
7	1	Long Island, North Fork	1	unknown	2.7 x 1.8	cordon spur/flat cane vsp	12	Haven
7	2	Long Island, North Fork	332	unknown	2.7 x 1.5	cordon spur/flat cane vsp	12	Haven
8	1	Long Island, North Fork	1	3309C	2.7 x 1.9	cordon spur vsp	7	Haven
8	2	Long Island, North Fork	1	SO4	2.7 x 1.9	cordon spur vsp	7	Haven
9	1	Lake Erie	unknown	3309C	2.7 x 1.4	two-tier flatbow vsp	5	Chenango
9	2	Lake Erie	unknown	3309C	2.7 x 1.4	two-tier flatbow vsp	5	Chenango
10	1	Lake Erie	327	3309C	2.7 x 1.9	cordon spur	8	Hornell
10	2	Lake Erie	327	3309C	2.7 x 1.9	cordon spur	8	Hornell

[a]m / row x m / vine.
[b]vsp: vertical shoot positioning.
[c]Vineyard aged was determined as years from planting in 2008.
[d] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions [Online WWW]. Available URL: “http://soils.usda.gov/technical/classification/osd/index.html”. USDA-NRCS, Lincoln, NE.

determined by dividing the number of total shoots per vine by in-row vine spacing. On divided canopy systems (i.e., Scott Henry) shoot density was determined by dividing the number of total shoots per vine by (in-row vine spacing x 2). At anthesis, shoot length and number of nodes per shoot were measured from node 1 to the shoot tip on 20 randomly selected shoots per vine. Average internode length was determined by dividing the average shoot length by the number of nodes. Enhanced Point Quadrat Analysis (EPQA) was conducted at 10 cm intervals in the fruiting zone at anthesis, 30 DAA, 50 DAA, and harvest, and calibrated exposure maps were created (Meyers and Vanden Heuvel 2008). On training systems with multiple fruiting zones (i.e., Scott Henry, two-tier flatbow as described by Reynolds and Vanden Heuvel, 2009), insertions were made along each tier. In 2009, EPQA was also performed at 30 cm above the fruiting zone (mid canopy) at 50 DAA and harvest. Measurements of photosynthetically active radiation (PAR, 400 - 700 nm) were taken in the fruiting zone with a AccuPAR LP-80 ceptometer (Decagon Devices, Cambridge, UK) on cloudless days between 10:30 and 3:00 pm. The probe was inserted parallel to the row in the interior of the canopy at the fruiting zone and mid canopy and the average of 4 readings was recorded. At 50 DAA and harvest, shoot diameters were measured midway between nodes 1 and 2 on 20 randomly selected shoots per vine with a Storm 3C301 Electronic Digital Caliper (Central Tools Incorporated, Cranston RI). At harvest, the number of nodes of ripe periderm were counted on 20 randomly selected shoots per vine.

Climatic measurements. PAR, rainfall, and air temperature were monitored from 1 May through harvest with Hobo Micro Station Data Loggers (Onset Computer Corporation, Bourne, MA) placed in each vineyard within 50 meters of an experimental panel. PAR, rainfall, and temperature were measured each minute and five minute averages were logged. Growing degree days (GDD) were determined as GDD = [(maximum daily temperature + minimum daily temperature) / 2] – 10 from 1 May to harvest. PAR was not measured in May and June in 2008.

Sampling and harvest parameters. At 30 and 50 DAA, 50-berry samples and at harvest, 200-berry samples were collected at random from each vine for chemical analyses, including IBMP quantification (Table 2). The berry samples were placed in storage bags and immediately frozen with liquid N_2 and stored at -23ºC until analyses were performed.

Table 2 Calendar dates for berry sampling from Cabernet franc vines by location and phenology in 2008 and 2009.

	2008			2009		
Location	**30 Days after anthesis**	**50 Days after anthesis**	**Harvest[b]**	**30 Days after anthesis**	**50 Days after anthesis**	**Harvest**
Site 1	18 July	7 August	19 October	17 July	6 August	18 October
Site 2	16 July	5 August	17 October	15 July	4 August	21 October
Site 3	16 July	5 August	14 October	15 July	4 August	23 October
Site 4	16 July	5 August	16 October	14 July	3 August	22 October
Site 5	16 July	5 August	16 October	14 July	3 August	22 October
Site 6	16 July	5 August	21 October	14 July	3 August	21 October
Site 7	17 July	6 August	24 October	24 July	14 August	3 November
Site 8	17 July	6 August	24 October	24 July	14 August	3 November
Site 9	21 July	10 August	13 October	-[a]	-	-
Site 10	21 July	10 August	13 October	-	-	-

[a]Not used in 2009.
[b]Commercial harvest date determined by grower/winery.

At each site, harvest date was determined by the respective winery and sample harvest occurred within two days of commercial harvest. Yield per vine was measured with a hanging scale accurate to 0.01 kg (model SA3N340, Salter Brecknell, Fairmont, MN) and cluster counts were recorded. Average cluster weight was calculated as yield divided by cluster count. Average fresh berry weight was determined by weighing the 200-berry harvest samples with a Setra SI410S balance (Setra Systems Inc., Boxborough, MA). In 2008, percent berry dry weight was calculated at harvest on a 50-berry subsample by grinding at 1600 strokes/min for two minutes using a 2000 Geno/Grinder (SPEX Certiprep, Metuchen, NJ), and drying a 20 g subsample in a drying oven at 60°C for 48 hours. Percent dry berry weight was calculated by dividing the initial subsample wet weight by the final dried weight. The remainder of the 50-berry sample was used for carbon isotope composition analysis and IBMP quantification. In 2009, average fresh berry weight was additionally determined at 30 and 50 days after anthesis using the 50-berry samples. During the winter, dormant cane pruning weight was recorded and crop load was calculated as yield divided by pruning weight. Average cane weight was determined as total pruning weight divided by number of canes.

Berry analysis for ºBrix, titratable acidity, and pH. A sub-sample of 150 mature berries was removed from the -23ºC freezer, placed in a 250-mL beaker and heated to 65 ºC for one hour in a water bath to redissolve tartrates, pressed through cheesecloth with a pestle, and the juice was collected for analyses. Soluble solids (ºBrix) were measured using a digital refractometer (model 300017; SPER Scientific, Scottsdale, AZ) with temperature correction. TA and pH were measured with an automatic titrater (Titrino model 798, Metrohm, Riverview, FL). TA was measured with a 5.0-mL aliquot of juice by titration against 0.1 N NaOH to pH 8.2 and expressed as tartaric acid equivalents.

Berry and leaf analysis for carbon isotope composition. Carbon isotope composition was determined on 10 g subsamples of berries collected at 50 DAA and harvest, and on 3 sun exposed leaves collected at 50 DAA and harvest from nodes 15, 16, and 17 from 3 randomly selected count shoots. Leaf and berry samples were dried in a drying oven at 60°C over a 48 hour period and ground with coffee grinder into a fine homogenous powder. Carbon isotope composition analysis was performed at the Cornell University Stable Isotope Laboratory using a Finnigan MAT Delta Plus (Bremen, Germany) isotope ratio mass spectrometer interfaced to a Carlo Erba NC2500 elemental analyzer. Carbon isotope composition was expressed as $\delta^{13}C = [(R_s - R_b) / R_b] \times 1000$, where $R_s = {}^{13}C/{}^{12}C$ ratio of the sample and $R_b = {}^{13}C/{}^{12}C$ ratio of the Pee Dee Belemnite) standard.

Berry analysis for 3-isobutyl-2-methoxypyrazine. IBMP analysis was conducted on 50-berry samples collected at 30 DAA, 50 DAA, and harvest. The extraction method was head space-solid phase micro extraction and quantification was performed by comprehensive two-dimensional gas chromatography time-of-flight mass spectrometry (GCxGC-TOF-MS) as described others (Ryona et al. 2009, Scheiner et al. 2010).

Fermentations. Fruit from each experimental plot (i.e., five-vine panel) was pooled for fermentation. Grapes were destemmed, crushed and separated into 7.6-L fermentation vessels. Musts lower than 22 °Brix were chapatalized to 22 °Brix to simulate standard regional industry practices. SO_2 was added at 50 mg/L and musts were inoculated with Lalvin ICV GRE yeast (Lallemand, Santa Rosa CA). Yeast nutrients were added as follows: GoFerm (0.15 g/L), Fermaid K (0.1 g/L), and diammonium hydrogen phosphate (1 g/L). Fermentation was carried out in a temperature controlled room at 20°C. The musts were punched down twice a day until the end of alcoholic fermentation (4 to 6 days). After the completion of alcoholic fermentation, an extended maceration was carried out for 5 days. Following extended maceration, wines were pressed through cheesecloth into 3.78 L carboys and inoculated for malolactic fermentation with Enoferm Alpha (Lallemand, Santa Rosa CA). At the end of malolactic fermentation, 60 mg/L of SO_2 was added to finished wines, followed by cold stabilization at 2°C for 60 days until bottling.

Wine analysis for 3-isobutyl-2-methoxypyrazine. At bottling, wine samples were collected for IBMP quantification by SPME extraction followed by GCxGC-TOF-MS. 5 mL of wine was transferred into a 20 mL SPME vial and diluted with 5 mL of Milli-Q water. 3 g of NaCl was added to the vial followed by an internal standard, [$^{2}H_2$]-IBMP, at 10 pg/g. Parameters for SPME and GCxGC-TOF-MS were similar to that for whole berries, but with an SPME extraction temperature of 40°C and a desorption temperature of 250°C.

Sensory evaluation. Ten wines from each vintage, selected to represent the widest range in IBMP concentration possible, were evaluated for intensity of herbaceous and fruity aromas. A 10-member panel consisting of 8 females and 2 males, ages 24 to 48 analyzed the 2008 wines and a 9-member panel (same panelists as 2008) consisting of 8 females and 1 male ages 25 to 49 analyzed the 2009 wines. Panelists were selected based on interest and availability. Prior to the first session, panelists were familiarized with the evaluation protocols and scorecard (anchored 9-point line scale). Aroma standards (Table 3) were provided to familiarize panelists with a range of herbaceous and fruity aromas.

In 2008, wines were stored at the New York State Agricultural Experiment Station wine cellar for 8 months (March to October) at 12°C. In 2009, wines were stored for 5 months (May to September) at room temperature (21°C) from April to

September to accelerate bottle aging. Twenty-four hours prior to testing, wines were moved to the testing area to equilibrate with the environment. Fifteen minutes prior to

Table 3 Attributes and reference standards for 2008 and 2009 sensory panels for wines made from individual panels from sites 2-8 and 10 (2008) and sites 1-3 and 5-8 (2009).

Aroma attribute	**Reference standard**[a]
Herbaceous	2 g bell pepper
Herbaceous	5 mL juice from Great Value canned asparagus (Bentonville, AR)
Herbaceous	5 mL juice from Great Value canned peas
Herbaceous	15 ug/L IBMP
Herbaceous	30 ug/L IBMP
Fruity	2 g Smuckers raspberry jam (Orrville, OH)
Fruity	2 g Smuckers blackberry jam
Fruity	2 g Smuckers strawberry jam

[a] Reference standards were prepared in 40 mL of Pinot noir base wine.

serving, 40 mL of wine was poured into clear, 250-mL tulip shaped glasses. Plastic covers were placed over the glasses to retain aromas. Sensory evaluation took place at the New York State Agricultural Experiment Station Sensory Evaluation Room under red lighting. Wines were evaluated for intensity of herbaceous and fruity aromas in triplicate using a randomized complete block design with order of presentation randomized within session. Five-wine sets were presented and panelists were instructed to evaluate each wine separately from left to right. Panelists waited 30 minutes and were then presented another set of 5 wines. All wines were tested in triplicate at separate sessions. Each panelist completed 3 sessions over a 3 week period.

Statistical analysis. Partial least squares regression (PLSR) was conducted with Minitab 15.0 statistical software (Minitab, Reading, MA). Data were normalized and the number of latent in each model was determined by the lowest predicted residual sum of squares (PRESS). The method of validation carried out was leave one out cross-validation. For model building, all X variables (122 in 2008 and 140 in 2009) were used to create an initial model (Table 4) and X variables with low regression coefficients were removed in an iterative process to generate the simplest model possible. For PLSR models for intensity of herbaceous and fruit wine aroma, panel averages were used for viticultural and climatic measurements. Principal components analysis (PCA) was conducted with Minitab and factor loadings were determined from the correlation matrix without rotation. One-way analysis of variance (ANOVA) and Welch's t-test were conducted using SPSS 19.0 statistical software (SPSS Inc., Chicago IL). Means were separated using Games-Howell test at the 5% significance level. Wine sensory data were subjected to the Mixed Models Procedure in SAS (SAS Institute Inc., Cary NC), with judge treated as a random effect and means were separated using the Tukey-Kramer procedure at the 5% significance level. Linear regression analysis was conducted using SAS (PROC REG).

Results

IBMP concentration in Cabernet franc berries. There were significant differences ($p < 0.001$) in IBMP concentration across sites at all phenological stages (30 DAA, 50 DAA, and harvest) in 2008 and 2009 (Table 5). In 2008 and 2009, IBMP concentrations increased at nine of ten sites and at seven of eight sites from 30 DAA to 50 DAA by an average of 62.7 and 82.0%, respectively. Oddly, IBMP decreased from 30 DAA to 50 DAA in 2009 at one vineyard (site 8) by an average of 71.6%. From 50 DAA to harvest, IBMP concentrations decreased at all sites by an average of 93 and 72% in 2008 and 2009, respectively. Although IBMP was significantly lower at 50 DAA at all sites in 2009 compared to 2008, only sites 5 and 8 had significantly lower concentrations and site 1 had significantly higher concentrations at harvest. IBMP concentrations in 2008 did not correlate with their respective sites in 2009 for any phenological stage (30 DAA, $R^2 = 0.09$; 50 DAA, $R^2 = 0.01$; harvest, $R^2 = 0.26$).

Multi-site PLSR models for IBMP concentrations at 50 DAA. IBMP concentration in berries at 50 DAA was best predicted by factors associated with vine vigor such as shoot diameter, pruning weight, average cane weight, shoot length, carbon isotope composition of leaves and berries, and July rainfall (Table 6). In all of the PLSR models except the 2009 LI model, the factors associated with vigor had positive correlation coefficients. In the 2009 LI model, pruning weight had a negative correlation coefficient, but measurements of shoot size (shoot diameter and shoot length) had positive coefficients. Carbon isotope composition of berries at 50 DAA had negative correlation coefficients while carbon isotope composition of leaves at 50 DAA had positive coefficients in all models except the LI 2008 model. In the All sites 2008 and FL 2008 models, average temperature from anthesis to 50 DAA was a predictor and had a positive regression coefficient. In the All sites 2009 and LI 2009 models, crop load was a predictor having a positive regression coefficient (Table 6). The multisite models with the best predictive ability were the LI 2009 model (R^2 validation = 0.86), followed by the All sites 2008 (R^2 validation = 0.69), and FL 2009 (R^2 validation = 0.68) models.

Table 4 X variables (measurements) included in initial 2008 and 2009 PLSR models to predict IBMP concentration at 50 DAA and log-fold decrease in IBMP from 50 DAA to harvest.

Vine		Crop [c]	Climate	
Metrics[a]	**Phenology[b]**	**Metrics**	**Metrics[d]**	**Phenology**
shoots per vine	AN, 50 DAA	yield	rainfall	May, June, Jul, Aug, Sept, 1 Oct-harvest, 1 May-50 DAA, AN-50DAA, 50 DAA-HAR, 65 DAA-HAR, 1 May-HAR
shoots per meter	AN, 50 DAA	cluster number	temperature	May, June, Jul, Aug, Sept, 1 Oct-15 Oct, 1 May-50 DAA, AN-50DAA, 50 DAA-15 Oct, 65 DAA-15 Oct, 1 May-15 Oct.
shoot length	AN	clusters per shoot	GDD	May, June, Jul, Aug, Sept, 1 Oct-harvest, 1 May-50 DAA, AN-50DAA, 50 DAA-HAR, 65 DAA-HAR, 1 May-HAR
nodes per shoot	AN	cluster weight	PAR	May, June, Jul, Aug, Sept, 1 Oct-harvest, 1 May-50 DAA, AN-50DAA, 50 DAA-HAR, 65 DAA-HAR, 1 May-HAR
internode length	AN	berry fresh weight		
shoot diameter	50 DAA, HAR	percent berry dry weight		
δ13C berries	50 DAA, HAR	pruning weight		
δ13C leaves	50 DAA, HAR	average cane weight		
LLN	AN, 30 DAA, 50 DAA, HAR	crop load		
PIL	AN, 30 DAA, 50 DAA, HAR	yield per shoot		
PIC	AN, 30 DAA, 50 DAA, HAR	°Brix		
PG	AN, 30 DAA, 50 DAA, HAR	titratable acidity		
OLN	AN, 30 DAA, 50 DAA, HAR	pH		
CEL	AN, 30 DAA, 50 DAA, HAR	°Brix / titratable acidity		
LEL	AN, 30 DAA, 50 DAA, HAR	°Brix*pH^2		
EP1	AN, 30 DAA, 50 DAA, HAR			
CEFA	AN, 30 DAA, 50 DAA, HAR			
CEFA*	AN, 30 DAA, 50 DAA, HAR			
LEFA	AN, 30 DAA, 50 DAA, HAR			
LEFA*	AN, 30 DAA, 50 DAA, HAR			
periderm	HAR			

[a]Nodes per shoot and internode length were measured in 2008 only; LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model; LLN, PIL, PG, OLN, LEL, EP1, LEFA, and LEFA* were measured at 30 cm above the fruiting zone in 2009 at 50 DAA and harvest; periderm: nodes of ripe periderm.

[b]Measurement at each phenological stage entered as a separate independent variable in models; AN: anthesis; DAA: days after anthesis, HAR: harvest.

[c]Crop measurements were taken at harvest; pruning was conducted during winter dormancy; berry weight was collected at 30 and 50 DAA, and harvest in 2009.

[d]GDD: growing degree days; PAR: photosynthetically active radiation; PAR was expressed as an accumulation of daily average; PAR was not measured in May and June in 2008.

Table 5 Mean IBMP concentration (picograms per gram of fresh fruit) in Cabernet franc berries at 30 and 50 days after anthesis and harvest for each site in 2008 and 2009.

	2008						2009						p-value (year)[e]		
Site	30 DAA[b]	SD	50 DAA	SD	Harvest	SD	30 DAA	SD	50 DAA	SD	Harvest	SD	30 DAA	50 DAA	Harvest
1	61.5cd[c]	19.7	102.5bc	24.7	4.5d	1.0	9.0d	2.1	29.2c	6.1	13.8a	6.7	< 0.001	< 0.001	0.002
2	112.1a	20.8	167.6a	37.2	7.6bd	3.0	22.4bc	5.5	35.4c	8.2	6.4ab	1.7	< 0.001	< 0.001	0.293
3	49.7cd	31.8	103.2bc	31.8	11.8ad	7.9	6.5d	3.0	17.4d	4.4	8.3ab	1.8	0.002	< 0.001	0.202
4	86.6ac	26.4	107.6b	16.3	9.5ac	2.9	14.6cd	6.7	32.8c	4.7	7.9ab	2.1	< 0.001	< 0.001	0.097
5	100.4ab	19.3	104.3bc	24.2	13.3ab	5.3	17.8c	4.0	51.1b	7.6	8.8ab	4.3	< 0.001	< 0.001	0.050
6	49.0d	15.6	107.4bc	23.3	11.5ab	3.1	32.7ab	8.7	60.1b	5.8	11.2a	3.9	0.012	< 0.001	0.816
7	101.0ab	16.3	191.5a	48.1	5.6cd	4.4	33.8a	3.1	87.0a	5.9	10.2ab	6.0	< 0.001	< 0.001	0.078
8	86.6ac	26.4	238.5a	48.6	12.1a	2.1	41.6a	6.1	11.8d	6.4	4.6b	2.7	< 0.001	< 0.001	< 0.001
9	74.8bd	20.0	108.4bc	25.0	1.3e	0.7	-	-	-	-	-	-	-	-	-
10	-[d]	-	74.0c	20.9	6.0cd	1.9	-	-	-	-	-	-	-	-	-
p[a]	< 0.001		< 0.001		< 0.001		< 0.001		< 0.001		< 0.001				

[a]p-value, comparison of mean IBMP concentration by site.
[b]DAA: days after anthesis.
[c]means followed by a different letter are significantly different at the 0.05 level of probability (Games-Howell).
[d]Not measured.
[e]Comparison of mean IBMP concentration by year (Welch's t-test).

Table 6 Partial least squares regression models: Basic statistics of the models and regression coefficients of X variables for the best model for IBMP concentration at 50 DAA (Y variable) in Cabernet franc berries at All sites, Finger Lakes sites, and Long Island sites in 2008 and 2009.

	Model					
	All sites 08	All sites 09	FL sites 08[f]	FL sites 09	LI sites 08[g]	LI sites 09
temp anthesis-50 DAA[a]	0.26	-	0.15	-	-	-
shoot dia 50 DAA[b]	0.23	-	-	-	0.78	0.39
δ13C berry 50 DAA	-0.16	-0.62	-0.45	-0.35	-	-0.27
δ13C leaf 50 DAA	-[e]	0.58	-	0.38	-0.20	0.29
shoot length	0.24	0.39	-	0.72	-	0.20
pruning weight	0.08	-	0.27	-	-	-0.43
average cane weight	0.11	-	-	-	-	-
rainfall July	-	-	0.66	-	-	-
berry weight 50 DAA	-	-	-	-	-	-0.27
crop load	-	0.44	-	-	-	0.48
NLV[c]	2	4	3	2	2	4
RMSE	32.0	16.2	21.6	8.3	39.2	9.4
R^2 (calibration)	0.71	0.46	0.64	0.73	0.50	0.95
RMSECV[d]	33.5	17.4	23.6	8.8	45.1	16.4
R^2 (validation)	0.68	0.37	0.57	0.69	0.34	0.86
P value	< 0.001	< 0.001	< 0.001	< 0.001	0.003	< 0.001

[a]temp: temperature; DAA: days after anthesis.
[b]dia: diameter.
[c]Number of latent variables.
[d]Root-mean-square error of cross-validation.
[e]Variable not in the model.
[f]FL: Finger Lakes.
[f]LI: Long Island.

Although all of the multi-site models contained multiple latent variables (i.e., independent variable matrices), but the first latent variable accounted for a large majority of the variability in IBMP concentration at 50 DAA (Table 7). The first latent variable in all of the models was characterized by measurements associated with vigor such as shoot diameter, shoot length, pruning weight, average cane weight, and rainfall in July; the second latent variable was characterized by carbon isotope composition of either the leaves or berries. Crop load and average berry weight loaded

Table 7 Partial least squares regression models: Loadings of the x variables for the first two components in the All sites, Finger Lakes sites, and Long Island sites models for IBMP concentration at 50DAA models.

	All sites 08		**All sites 09**		**FL sites 08[e]**		**FL sites 09**		**LI sites 08[f]**		**LI sites 2009**	
X variable	**LV1[c]**	**LV2**	**LV1**	**LV2**	**LV1**	**LV2**	**LV1**	**LV2**	**LV1**	**LV2**	**LV1**	**LV2**
temp anthesis-50 DAA[a]	0.44	0.35	-	-	0.50	-0.59	-	-	-	-	-	-
shoot dia 50 DAA[b]	0.46	0.05	-	-	-	-	-	-	0.93	0.16	-0.41	0.47
δ13C berry 50 DAA	-0.13	0.55	0.30	-1.17	-0.17	-0.87	0.34	-0.95	-	-	-0.13	-0.85
δ13C leaf 50 DAA	-[d]	-	0.72	-0.21	-	-	0.69	-0.22	0.52	-0.99	-0.19	0.64
shoot length	0.46	0.23	0.73	0.10	-	-	0.72	0.21	-	-	-0.27	0.55
pruning weight	0.40	-0.55	-	-	0.54	-0.58	-	-	-	-	-0.54	-0.11
average cane weight	0.45	-0.48	-	-	-	-	-	-	-	-	-	-
rainfall July	-	-	-	-	0.68	-0.07	-	-	-	-	-	-
berry weight 50 DAA	-	-	-	-	-	-	-	-	-	-	-0.48	-0.27
crop load	-	-	-0.19	-0.06	-	-	-	-	-	-	0.48	-0.10
Explained variance (%)	68.9	2.0	27.1	16.2	59.2	4.5	60.0	12.5	61.0	-	77.3	13.7

[a]temp: temperature; DAA: days after anthesis.
[b]dia: diameter.
[c]LV: latent variable.
[d]Not included in the model.
[e]FL: Finger Lakes.
[f]LI: Long Island.

to the same latent variables as the factors associated with vine vigor, indicating a correlation between the factors.

Single-site PLSR models for IBMP concentrations at 50 DAA. Constructing single site models eliminated factors associated with climate and allowed for an in-depth evaluation of variability in berry IBMP concentration within individual vines. Similar to the multi-site models, factors associated vine vigor were predictors in all of the single-site models (Tables 8 and 9). Although cluster exposure flux availability (CEFA) was not a predictor in the multi-site models, it contributed to four of the ten single-site models in 2008 having a negative correlation coefficient (Table 8). However, CEFA loaded on the same latent variables (data not shown) as the factors associated with vigor indicating a correlation among the factors. It was not possible to generate single-site models that predicted IBMP concentration at 50 DAA (R^2 validation range = 0.11 to 0.64, average R^2 validation = 0.356) as well as the 2008 multisite models (R^2 validation range = 0.34 to 0.86, average R^2 validation = 0.530).

The 2009 single-site models constructed for IBMP concentration at 50 DAA had a higher predictive power than the multi-site models. The R^2 validation of the 2009 single site models ranged from 0.29 to 0.93 and averaged 0.66. Carbon isotope composition in either the leaves and/or berries was a predictor in 7 of the 8 models. Similar to the previous PLSR models for IBMP concentration at 50 DAA, the first latent variable accounted for the majority of the variance (data not shown), and was characterized by factors associated with vine vigor. In 2009, EPQA was conducted in the canopy 30 cm above the fruiting zone and LLN at 50 DAA was a factor in two of the models. Average berry weight at 50 DAA was also measured in 2009 and was a factor in four of the PLSR models.

Table 8 Partial least squares regression models: Basic statistics of the models and regression coefficients of X variables for the best model for IBMP concentration at 50 DAA (Y variable) for individual sites in 2008.

	Model									
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**	**Site 9**	**Site 10**
shoot dia 50 DAA[a]	-[f]	-	-	0.26	-	-	-	0.39	0.40	-
δ13C berry 50 DAA	-	-0.38	-	-0.30	-1.29	-0.75	-0.42	-	-	-
δ13C leaf 50 DAA	-	-	-	-0.12	-	-	-	-	-	-
shoot length	-	-	-0.27	-	-	-	-	-	-	-
pruning weight	0.83	0.40	0.31	-	-	-	-	-	-	0.42
average cane weight	-	-	-	0.31	-	0.21	-	-	-	0.40
clusters per shoot	0.08	-	-	0.13	-	-	-	-0.57	-	-
berry weight harvest	-	-	0.30	-	-	-	-	-	-	-
crop load	-	-	-	-	-	-	-	-	-0.31	-
periderm[b]	-	-	-	-	0.86	-	-	-	-	-
nodes per shoot	-	-	-	0.27	-	-	-	-	-	-
CEFA 30 DAA[c]	-0.38	-	-	-	-	-	-	-	-	-
CEFA 50 DAA	-	-0.29	-	-	-	-	-0.42	-	-0.22	-
NLV[d]	2	1	1	1	2	2	1	2	1	1
RMSE	15.4	23.2	21.2	9.3	12.2	16.2	32.0	32.8	19.2	14.54
R^2 (calibration)	0.74	0.69	0.61	0.71	0.80	0.63	0.48	0.65	0.48	0.28
RMSECV[e]	24.2	32.0	27.3	13.6	16.38	19.8	39.1	45.6	25.1	17.5
R^2 (validation)	0.37	0.33	0.35	0.39	0.64	0.44	0.23	0.31	0.11	0.39
P value	0.033	0.005	0.008	0.002	0.003	0.032	0.026	0.027	0.026	0.011

[a]dia: diameter; DAA: days after anthesis.
[b]periderm: nodes of ripe periderm.
[c]CEFA: cluster exposure flux availability.
[d]Number of latent variables.
[e]Root-mean-square error of cross-validation.

Table 9 Partial least squares regression models: Basic statistics of the models and regression coefficients of X variables for the best model for IBMP concentration at 50 DAA (Y variable) for individual sites in 2009.

	Model							
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
shoot dia 50 DAA[a]	-[f]	-	-	-	-	-	-0.33	0.26
δ13C berry 50 DAA	-0.31	-0.68	-0.44	-	-	0.14	-0.67	0.30
δ13C leaf 50 DAA	-	-1.40	-	-	0.34	0.18	0.26	0.33
shoot length	0.59	-	-	-	-	-	-	-1.19
pruning weight	-	-	-	-	-	-0.43	-0.39	-
average cane weight	-	-	-	0.46	-	-	-	-
clusters per shoot	-	-	-	-	-	0.22	-	-0.88
berry weight 50 DAA	0.63	-	-	-0.42	0.33	0.16	-	-
crop load	-	-	-	-	-0.39	0.40	-	-
LLN mid can 50 DAA[b]	-	-	0.77	0.46	-	-	-	-
CEFA 30 DAA[c]	-	-	-	-	-0.33	-	-	-
NLV[d]	3	2	1	2	1	2	3	5
RMSE	1.7	4.0	2.3	2.4	3.6	2.6	0.06	1.0
R^2 (calibration)	0.95	0.76	0.76	0.76	0.80	0.84	0.99	0.99
RMSECV[e]	3.9	5.8	3.0	3.1	6.7	4.2	3.1	3.0
R^2 (validation)	0.74	0.62	0.62	0.62	0.29	0.59	0.93	0.90
P value	< 0.001	0.002	0.001	0.007	0.001	0.002	0.006	<0.001

[a]dia: diameter; DAA: days after anthesis.
[b]LLN: leaf layer number.
[c]CEFA: cluster exposure flux availability.
[d]Number of latent variables.
[e]Root-mean-square error of cross-validation.
[f]Variable not in the model.

Multi-site PLSR models for log-fold decrease in IBMP concentration from 50 DAA to harvest. It was not possible to generate models for log-fold decrease in IBMP from 50 DAA to harvest with a high predictive power (Table 10). The R^2 validation of the models ranged from 0.10 to 0.50 and averaged 0.33. In the model with the strongest power (LI 08), shoot length and clusters per shoot were the only factors included, both having negative regression coefficients. Shoot length loaded most heavily on the first latent variable which accounted for 49.8 % of the variance (Table 11). In all of the multi-site models for log-fold decrease in IBMP from 50 DAA to harvest, one or two latent variables were extracted.

Single-site PLSR models for log-fold decrease in IBMP concentration from 50 DAA to harvest. In comparison with the multi-site models, the single-site models for log-fold decrease in IBMP concentration from 50 DAA to harvest had a higher predictive power (Table 12 and 13). The range in R^2 validation for the 2008 and 2009 single-site models was 0.75 to 0.95 and 0.02 to 0.86, respectively. In all of the 2008 models, at least one measurement associated with vine vigor was a factor. In eight of the ten models, carbon isotope composition of mature berries was a factor. The relationship between log-fold decrease in IBMP and measurements associated with vine vigor and carbon isotope composition were site dependent having both positive and negative regression coefficients. In all of the 2009 single-site models, factors associated with vine vigor, carbon isotope composition of berries, or crop to vine size were predictors in all of the models. Similar to the 2008 models, the relationship between the predictors and log-decrease in IBMP were site dependent. It was not possible to construct a satisfactory model to predict log-fold decrease in IBMP at site 6 and site 8 (R^2 validation < 0.10).

Table 11 Partial least squares regression models: Loadings of the x variables for the first two components in the log-fold decrease in IBMP from 50 DAA to harvest models.

	All sites 08		**All sites 09**		**FL sites 08[f]**		**FL sites 09**		**LI sites 08[g]**		**LI sites 2009**	
X variable	**LV1[d]**	**LV2**	**LV1**	**LV2**	**LV1**	**LV2**	**LV1**	**LV2**	**LV1**	**LV2**	**LV1**	**LV2**
temp 65 DAA- harvest	0.58	-0.35	-	-	-	-	-	-	-	-	-	-
shoot dia harvest[a]	-[e]	-	0.58	-	-	-	0.47	-	-	-	-	-
δ13C berry 50 DAA[b]	-0.40	-0.02	-	-	-	-	-	-	-	-	-	-
δ13C berry harvest	-0.43	0.27	-	-	-0.64	-	-	-	-	-	-	-
shoot length	0.50	-0.43	0.65	-	-	-	0.44	-	-0.86	0.52	-	-
pruning weight	-	-	-	-	-	-	-	-	-	-	-0.71	-
average cane weight	-	-	-	-	-	-	0.46	-	-	-	-0.71	-
shoots per meter 50 DAA	0.42	0.46	-	-	0.72	-	-	-	-	-	-	-
yield per shoot	-	-	0.51	-	-	-	0.38	-	-	-	-	-
periderm[c]	-	-	-	-	-	-	0.48	-	-	-	-	-
crop load	0.00	0.68	-	-	0.27	-	-	-	-	-	-	-
periderm	-	-	-	-	-	-	-	-	-	-	-	-
clusters per shoot	-	-	-	-	-	-	-	-	-0.51	-0.85	-	-
Explained variance (%)	33.0	3.0	17.3	-	0.32	-	47.0	-	49.9	0.1	17.3	-

[a]dia: diameter.
[b]DAA: days after anthesis.
[c]periderm: nodes of ripe periderm.
[d]LV: latent variable.
[e]Not included in the model.
[f]FL: Finger Lakes.
[g]LI: Long Island.

Table 12 Partial least squares regression models: Basic statistics of the models and regression coefficients of X variables for the best model for log-fold decrease in IBMP from 50 DAA to harvest (Y variable) for individual sites in 2008.

	Model									
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**	**Site 9**	**Site 10**
shoot dia harvest[a]	-[d]	-	-	-	-	-	-	-	-0.63	-
δ13C berry harvest	0.36	0.97	0.24	-	-0.48	0.48	-	-0.85	0.42	0.48
shoot length	0.14	-	-0.25	-	-	-	-	-	-	-
pruning weight	-	-	-	-	0.54	-	0.25	-0.55	-	-
average cane weight	0.24	-	-0.44	-0.53	-	0.50	0.24	-	-	1.36
yield per shoot	0.17	-	0.25	-	-	-	-	-0.77	-	-
crop load	-	-	-	0.50	-	1.22	0.34	-	-	1.09
periderm	0.46	0.31	-0.27	-	0.33	-	-	-	-0.71	-
clusters per vine	0.38	-	0.14	-	-	-	-	-	-	-
titratable acidity	-	-	-	-0.44	-0.53	-	-0.30	-	-	-
NLV[c]	2	2	1	2	2	3	1	3	3	3
RMSE	0.04	0.01	0.02	0.01	0.01	0.01	0.03	0.01	0.01	0.01
R^2 (calibration)	0.86	0.92	0.83	0.75	0.83	0.90	0.85	0.88	0.90	0.95
RMSECV[d]	0.14	0.01	0.06	0.01	0.04	0.02	0.05	0.01	0.02	0.01
R^2 (validation)	0.56	0.92	0.61	0.52	0.35	0.59	0.75	0.69	0.75	0.90
P value	0.01	<0.001	<0.001	0.008	0.002	0.002	<0.001	0.003	0.002	<0.001

[a]dia: diameter.
[b]DAA: days after anthesis.
[c]Number of latent variables.
[d]Root-mean-square error of cross-validation.
[e]Variable not in the model.

Table 13 Partial least squares regression models: Basic statistics of the models and regression coefficients of X variables for the best model for log-fold decrease in IBMP from 50 DAA to harvest (Y variable) for individual sites in 2009.

	Model							
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
shoot dia 50 DAA[a]	-[f]		-0.31	-	-	-	-	-
δ13C berry 50 DAA	-	-0.33	-	-	0.24	-	-	-
δ13C berry harvest	-	-0.64	-	0.46	-	-	0.83	-0.25
δ13C leaf harvest	-	-	-	-	-	-0.54	-	-
shoot length	-	-	-	-	0.44	-	-	-
berry weight 50 DAA	-	-	-	-	-	-0.43	-	-0.20
pruning weight	0.25	0.57	-	-	-	-	0.73	-0.19
shoots per meter 50 DAA	-	-	-	-	-	-0.43	-	-
periderm[b]	-	1.38	-0.38	0.36	0.18	-	-	-
crop load	-0.43	0.47	-1.17	-0.64	-0.47	-	-	-
titratable acidity	-0.65	-	-	-0.60	-0.33	-	-	-
LLN mid canopy harvest	-	-	-	-	-	-	-	0.26
NLV[d]	1	3	3	2	2	3	2	1
RMSE	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06
R^2 (calibration)	0.74	0.89	0.95	0.87	0.83	0.56	0.97	0.48
RMSECV[e]	0.01	0.01	0.01	0.03	0.03	0.03	0.01	0.10
R^2 (validation)	0.56	0.65	0.86	0.45	0.47	0.02	0.58	0.08
P value	0.001	0.003	0.001	0.001	0.002	0.151	0.025	0.026

[a]dia: diameter,DAA: days after anthesis.
[b]periderm: nodes of ripe periderm.
[c]CEFA: cluster exposure flux availability.
[d]Number of latent variables.
[e]Root-mean-square error of cross-validation.
[f]Variable not in the model.

Principal components analysis of X variables in PLSR models. PCA was conducted separately on the variables in used in the 2008 and 2009 PLSR models to evaluate the relationship between these factors (Figure 1). Principal component (PC) 1 and 2 of the 2008 variables (Figure 1A) accounted for 40 and 14% of variance, respectively. Measurements associated with vine vigor (shoot diameter at 50 DAA and harvest, shoot length, pruning weight, average cane weight, periderm) positively loaded (< -0.20) on PC 1 in addition to berry weight at harvest, temperature AN-50 DAA, temperature 65 DAA-harvest, and CEFA 50 DAA indicating a positive correlation between the variables. Measurements of crop to vine size (crop load, clusters per shoot, and yield per shoot) negatively loaded (> 0.20) on PC 1 indicating an inverse relationship with the factors associated with vigor. On PC 2, titratable acidity and carbon isotope composition of leaves at 50 DAA had relatively high negative loadings (< -0.20) and shoots per meter 50 DAA, shoot length, temperature anthesis-50 DAA, temp 65 DAA-harvest, clusters per shoot, and CEFA 50 DAA had relatively high positive loadings (> 0.20). Carbon isotope composition of berries at 50 DAA and harvest both loaded heavily on PC 4 and PC 6. In the PCA of the 2009 variables, PC 1 and 2 accounted for 35 and 20% of the variance (Figure 1B). Factors associated with vine vigor (pruning weight, average cane weight, periderm, and shoot diameter 50 DAA) and carbon isotope composition of berries at harvest positively loaded (> 0.30) and shoots per meter 50 DAA negatively loaded (< 0.30) on PC 1. On PC 2, shoot diameter 50 DAA, clusters per shoot, crop load, and carbon isotope composition berries harvest, were positively loaded (> 0.30) and shoots per meter 50 DAA were negatively loaded (< 0.30).

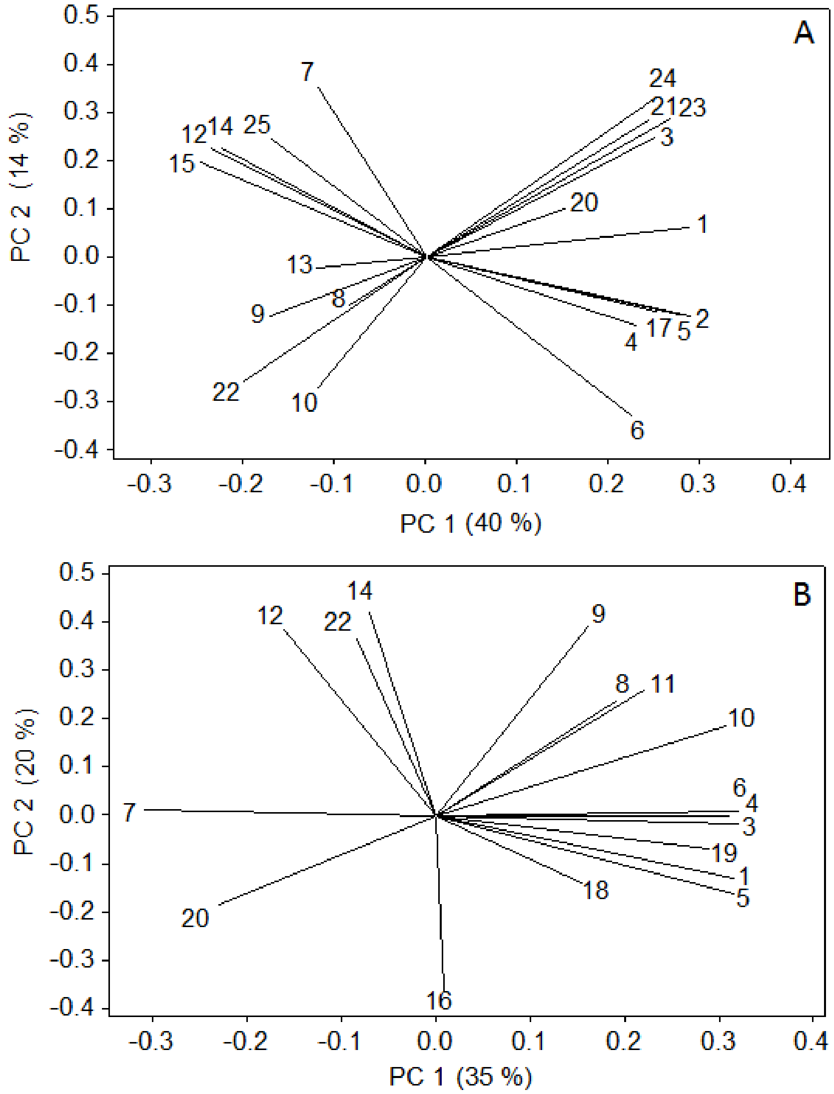

Figure 1 Projection of X variables used in (A) 2008 and (B) 2009 PLSR models on principal components 1 and 2. Numbers indicate: 1 shoot diameter 50 days after anthesis (DAA), 2 shoot diameter harvest, 3 shoot length, 4 pruning weight, 5 average cane weight, 6 nodes of ripe periderm, 7 shoots per meter 50 DAA, 8 δ13C berry 50 DAA, 9 δ13C berry harvest, 10 δ13C leaf 50 DAA, 11 δ13C leaf harvest, 12 crop load, 13 yield per shoot, 14 clusters per shoot, 15 clusters per vine, 16 berry weight 50 DAA, 17 berry weight harvest, 18 leaf layer number mid canopy 50 DAA, 19 leaf layer number mid canopy harvest, 20 cluster exposure flux availability 30 DAA, 21 cluster exposure flux availability 50 DAA, 22 titratable acidity, 23 temperature anthesis – 50 DAA, 24 temperature 65 DAA – harvest, 25 July rainfall.

Sensory evaluation of wines. The concentration of IBMP in grapes was significantly correlated with their concentrations in their respective wines, as has been previously observed (Ryona et al. 2009). IBMP concentrations ranged from undetectable to 17 pg/g and undetectable to 13 pg/g in the 2008 and 2009 wines, respectively (Figure 2). There was no correlation ($R^2 = 0.03$ and 0.02) between IBMP concentration and intensity of herbaceous aroma of wines of either year.

Significant differences were observed between the 2008 wines for intensity of herbaceous aromas and 2009 wines for intensity of herbaceous and fruit aroma (Table 14). There was a significant panelist x wine interaction for intensity of fruit aroma in the 2009 wines indicating a discrepancy between panelists on relative wine ratings.

PLSR models for intensity of herbaceous and fruit aroma. PLSR models were constructed to predict the intensity of herbaceous aroma in the 2008 and 2009 wines and intensity of fruit aroma in the 2009 wines (Table. The R^2 validation of the 2008 herbaceous, 2009 herbaceous, and 2009 fruit models were 0.76, 0.73, and 0.32, respectively. In the 2008 herbaceous model, carbon isotope composition of mature berries had a positive regression coefficient (0.76), followed by shoot length (-0.55), Brix*pH^2 (-0.53) and pH (-0.29). In the 2009 herbaceous model, carbon isotope composition of mature berries and leaves at harvest had the highest regression coefficients (1.77, -1.44) and average cane weight had a negative correlation coefficient (-1.02). It was not possible to construct a satisfactory model to predict the intensity of fruit aroma in the 2009 wines (R^2 validation = 0.32).

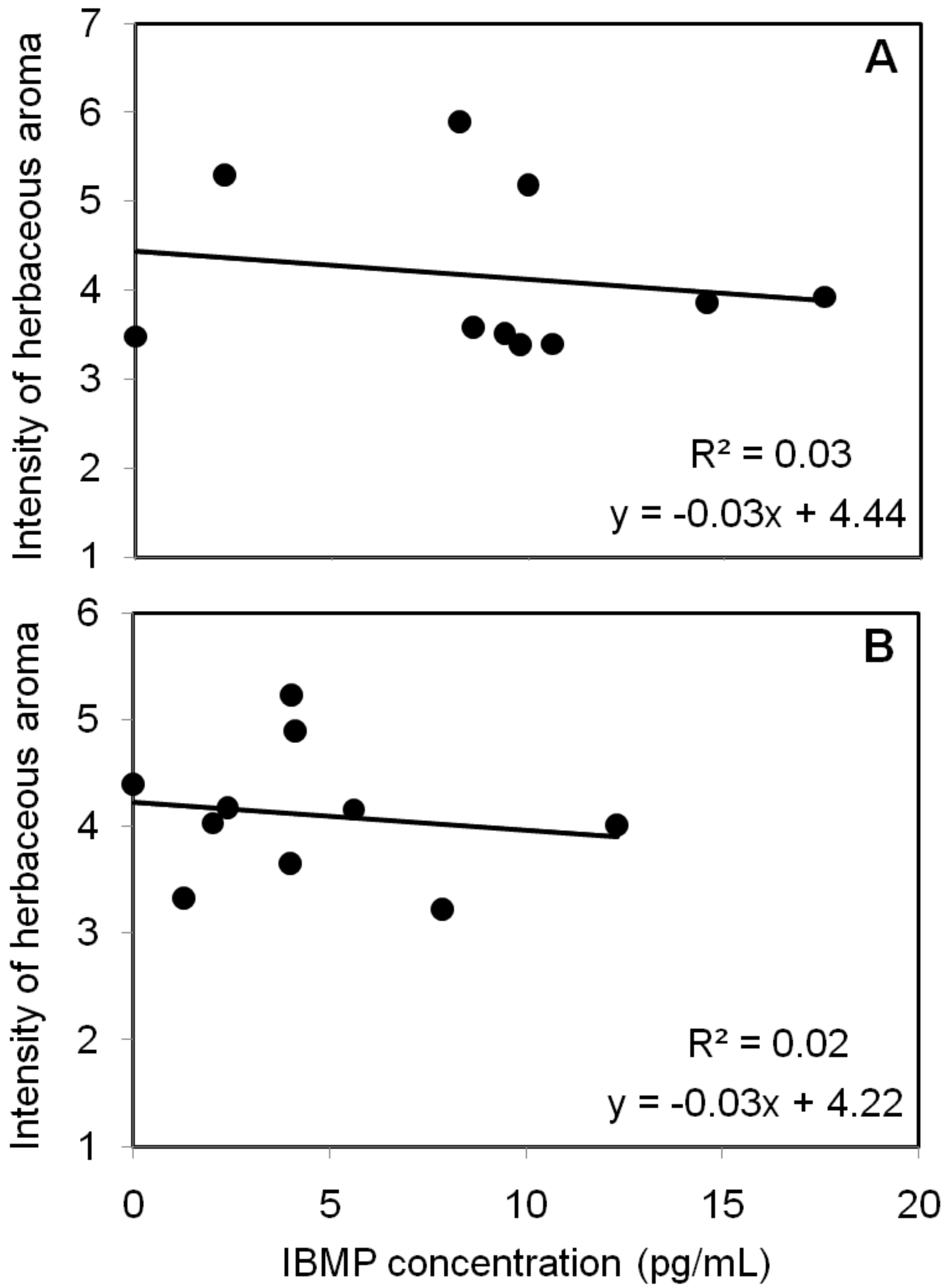

Figure 2 Correlation between IBMP concentration and intensity of herbaceous aroma for **(A)** 2008 and **(B)** 2009 Cabernet franc wines.

Table 14 Analysis of variance of 2008 and 2009 wine ratings: p-values, degrees of freedom and mean squared error.

	P-value						
	Panelist (P)	Wine (W)	Rep (R)	W X P	P X R	W X R	MSE[b]
2008							
herbaceous	0.001	<0.001	0.049	0.320	0.256	0.899	3.99
fruity	<0.001	0.230	0.802	0.298	0.676	0.199	4.08
2009							
herbaceous	<0.001	<0.001	0.380	0.157	0.199	0.174	2.86
fruity	0.001	<0.001	0.133	<0.001	0.957	0.089	2.51
df[a]	8	9	2	72	16	18	144

[a]df: degrees of freedom.
[b]MSE: mean squared error.

Table 15 Partial least squares regression models: Basic statistics of the models and regression coefficients of X variables for the best model for intensity of herbaceous and fruity aroma (Y variable) for 2008 and 2009 wines.

	Model		
	2008 herbaceous	2009 herbaceous	2009 fruit
δ13C berry harvest	0.76	1.77	0.67
δ13C leaf harvest	-[d]	-1.44	-
shoot length	-0.57	-	0.16
LLN anthesis[a]	-	-	0.66
periderm	-	-	-0.80
average cane weight	-	-1.02	-
Brix*pH^2	-0.53	-	-
pH	-0.29	-	-
NLV[b]	2	3	2
RMSE	0.10	0.10	0.24
R^2 (calibration)	0.92	0.88	0.72
RMSECV[c]	0.32	0.20	0.60
R^2 (validation)	0.76	0.73	0.32
P value	0.002	0.026	0.044

[a]LLN: leaf layer number.
[b]Number of latent variables.
[c]Root-mean-square error of cross-validation.
[d]Variable not in the model.

Discussion

Grapes and wine produced in cool regions and cool years are reported to have higher IBMP concentrations (Allen et al. 1994, Belancic and Agosin 2007, Falcao et al. 2007, Kotseridis et al. 1998, Lacey et al. 1991) but we did not observe this phenomenon. In 2008 and 2009, the average growing degree accumulation (^{o}C) from 1 May to 50 DAA, across sites was 894 and 799, respectively, and IBMP concentrations at 50 DAA were significantly higher (68.5%) at all sites in 2008. In concordance with several other groups (Kotseridis et al. 1998, Hashizume and Umeda 1996, Lacey 1991), decrease in IBMP from 50 DAA to harvest was lower in the cooler year (2009), but concentrations at harvest were still significantly lower in 2009 at 2 sites and not significantly different at 5 sites as a result of the reduced accumulation. We constructed PLSR models, combining all sites and years to predict IBMP at 50 DAA and log-fold decrease in IBMP from 50 DAA to harvest (data not shown), and temperature was an important predictor in both models. Average temperature from anthesis to 50 DAA positively correlated with IBMP concentration at 50 DAA and average temperature from 50 DAA to harvest positively correlated with the log-fold decrease in IBMP, suggesting that both pre- and postveraison temperatures are an important determinant of final IBMP concentrations. Grapes may accumulate more IBMP in warmer climates, but degradation occurs more rapidly under warmer ripening conditions, and warmer regions typically have longer growing seasons and consequentially a longer postveraison period for IBMP degradation to occur. The earlier studies mentioned above have focused on temperature during the ripening period and quantified IBMP after the onset of degradation, and have not studied the impact of temperature on IBMP accumulation.

There was significant variation within and among sites in IBMP concentrations at both pre-veraison time points and harvest, but the site-to-site variation was larger. The PLSR models indicated that IBMP was predicted by factors associated with vine vigor and crop to vine size. In general, vines with higher vigor as measured by greater shoot length and diameter, cane weight, and other associated factors accumulated more IBMP. The most widely used single in the IBMP concentration at 50 DAA models was the carbon isotope ratio of berries. The carbon isotope ratio ($\delta^{13}C$) of grape leaves and berries correlates with pre-dawn leaf water potential and is indicator of vine water status (de Sauza et al. 2003, Gaudillere et al. 2002). In response to stress (e.g. drought), the stomatal aperture decreases resulting in depletion of ^{12}C and less discrimination against the heavier carbon isotope, ^{13}C (Farquhar et al. 1989), resulting in an increase in $\delta^{13}C$. Berry $\delta^{13}C$ was a better predictor of IBMP concentration at 50 DAA. Interestingly, leaf $\delta^{13}C$ had an opposite regression coefficient of berry $\delta^{13}C$ in several of the models. Because we only sampled sun exposed leaves from nodes 15, 16, and 17, it is likely that the $\delta^{13}C$ of berries was a better representation of the whole canopy over berry development. In all but two of the models for IBMP at 50 DAA, berry $\delta^{13}C$ was negatively correlated with IBMP. Thus, vines with higher discrimination (i.e., less water stress) tended to be more vigorous and have fruit with higher IBMP concentrations. However, in the multisite models, $\delta^{13}C$ loaded heavily on a different latent variable than of the factors associated with vine vigor. This discrepancy could potentially be explained by other factors that influence vigor such as bud number, nutrient availability, rootstock, and crop level. It is likely that these factors were more variable across sites than within a single vineyard.

Although factors associated with vine vigor explained the majority of variability in IBMP concentration at 50 DAA across and within sites in each year, the higher preveraison IBMP concentrations observed in 2008 may attributed to higher preveraison temperatures and not vigor. In 2009, vines were more vigorous (average cane weight across sites = 65.7 g) than the previous year (average cane weight across sites = 46.1 g), but accumulated less IBMP possibly resulting from lower preveraison temperatures.

Cluster light exposure can reduce IBMP accumulation (de Boubee et al. 2002, Ryona et al. 2008, Noble et al. 1995, Allen et al. 1996, Marais et al. 1999), but it was not a predictor in any of the multisite models for IBMP concentration at 50 DAA. Because canopy management practices (e.g. leaf removal, shoot thinning, shoot positioning, hedging) were imposed at different phenological stages and differing intensities across sites, it is possible that we did not capture the true dynamics of exposure during the preveraison period. In five of the single-site models for IBMP at 50 DAA, cluster light exposure, reported as cluster exposure flux availability (CEFA), was negatively correlated with IBMP, but loaded to the same latent variables as the factors associated with vigor. Thus, the correlation with CEFA could not be distinguished from that of vigor in these models. However, PCA analysis did not indicate a relationship between CEFA at 30 DAA and vigor in either year, although CEFA at 50 DAA positively correlated with vigor in 2008. This could potentially be explained by differences in canopy management from site to site. The lack of predictive ability of cluster light exposure in the multi-site study is not surprising; the differences in IBMP between fully shaded and fully exposed fruit within a vineyard do not usually exceed a factor of 2 (Marais et al. 1999, Ryona et al. 2008, Scheiner et al. 2010). However, the variation in IBMP among and within regions, including in our current study, is routinely reported to exceed an order of magnitude (Allen et al. 1994, Noble et al. 1995, Ryona et al. 2008). Thus, while cluster light exposure may be an important variable within some sites, it is superseded by other factors in cross-site comparisons.

In general, IBMP concentrations in Cabernet franc followed the previously reported pattern over the growing season of preveraison accumulation followed by postveraison degradation. However, in 2009, we observed a 72% decrease in IBMP from 30 DAA to 50 DAA at site 8. This is in contrast to several reports that IBMP peaks in concentration around 0 to 14 days prior to veraison (de Boubee et al. 2000, Hashizume and Samuta 1999, Sala et al. 2004, Ryona et al. 2008). At site 8, the 50 DAA samples were collected approximately 10 days prior to veraison indicating that IBMP did decrease earlier than previously reported. Although berries increased in weight from 30 to 50 DAA, the observed decrease in IBMP is not solely attributable to dilution, as berry weights increased by 42% but IBMP decreased by 72%. The vines at site 8 were highly vigorous and thinned to less than one cluster per shoot (average yield/pruning weight = 1.18, average clusters/shoot = 0.6) at approximately 20 DAA, but we cannot establish that this practice led to an early decrease in IBMP. At harvest, °Brix and TA were 21.6 and 7.3 g/L which is not indicative advanced maturity.

In comparison to IBMP accumulation, our attempts to model IBMP decrease across sites were less successful, as several factors important to modeling within site IBMP decrease had inconsistent behavior from site to site. For example, factors associated with vine vigor were positively correlated with IBMP decrease in four of the six multisite models, but both negative and positive correlations were observed within sites. Because the measurements of vine vigor were taken prior to veraison, we cannot establish if they were an accurate representation of vine growth after veraison. However, we did observe that vines at some sites were still actively growing at harvest and vine vigor is shown to delay fruit maturity (Carbonneau 1996). Thus, the opposing relationship between these measurements and decrease in IBMP from site-to-site may have resulted from differences in fruit maturation as affected by vigor. In accordance, de Boubee et al. (2000) tentatively correlated a decreased rate in IBMP degradation in Cabernet Sauvignon to late season vine growth induced by high rainfall. It is also well established that overcropping can reduce fruit maturation (Jackson and Lombard 1993) and in eleven of the single-site models for log-fold decrease in IBMP, several measurements of crop to vine size (crop load, yield per shoot, clusters per shoot) were predictors that, depending on the site, positively or negatively correlated with percent decrease in IBMP. At three of the five sites where measurements of crop to vine size (crop load, yield per shoot, clusters per shoot) negatively correlated with log-fold decrease in IBMP, fruit maturity was positively correlated with log-fold decrease in IBMP indicating that vines with higher crop to vine size (crop load, yield per shoot, clusters per shoot) had less mature fruit. Several groups have reported correlations between IBMP concentrations and fruit maturity indices such as Brix (Hashizume and Umeda 1996) and malic acid (de Boubee et al. 2000, Chapman et al. 2004, Hashizume and Umeda 1996, Kotseridis et al. 1999) and in six of the single site models, log-fold decrease in IBMP positively correlated with fruit maturation. However, the relationship with vigor is less clear.

Although the concentration of IBMP in grapes was correlated with the IBMP concentration in wines, the intensity of herbaceous aroma of the Cabernet franc wines did not correlate with IBMP. While some authors have reported a correlation between IBMP and herbacousness in wines (Allen et al. 1991, de Boubee et al. 2000), these studies included some wines with IBMP at least two-fold over its reported sensory threshold, 10-15 ng/L (de Boubee et al. 2000, Kotseridis et al. 1998, Maga 1990). In our work, IBMP ranged from well below to just above the sensory detection threshold in red wine, suggesting that IBMP is not a useful proxy for herbaceousness in New York State Cabernet franc in the sites under study. Similar observations have been made for California Cabernet Sauvignon with comparable IBMP concentrations (Chapman et al. 2004). Fruity aromas can mask the perception of herbaceous aromas, and vice versa (Hein et al. 2009, Campo et al. 2006, Pickering et al. 2004), and we observed a similar inverse correlation between fruity and vegetal aromas in our work (data not shown). Thus, the difference in vegetal aroma intensity may relate to an absence of fruity aromas or the presence of other herbaceous odorants, e.g. C6 alcohols (Campo et al. 2006). Wines produced from grapes not known to produce significant levels of IBMP can also have herbacesous aromas (Guinard and Cliff 1987, Noble and Shannon 1987). We modeled the intensity of herbaceous aroma using viticultural and climatic measurements, and the single most important predictor was carbon isotope composition of mature berries. Wines made from grapes with a lower vine water status as indicated by the carbon isotope composition were rated as having the highest intensity of herbaceous aromas. Shoot length and average cane weight negatively correlated with herbaceous aroma. This observation is surprising, considering that lower water availability and reduced vine growth have been associated with less herbaceous aromas (Chapman et al. 2005, Jackson and Lombard 1993) and more generally with improved red wine quality (Van Leeuwen 2010). However, many of these previous studies investigated systems with a large range of water availabilities, either by natural causes or cultural practices i.e. deficit irrigation. In our current study, the range of $\delta^{13}C$ values within a year was <2‰, less than in some previous studies (de Sauza et al. 2003, Gaudillere et al. 2002). Additionally, all sites had $\delta^{13}C < -26‰$ indicating that all of the sites under study likely had similarly high water availability. Rainfall over the two years of study (1 May – 15 October) ranged from 349 to 572 mm, supporting this hypothesis. The weaker predictive ability of water status for wine quality in years with higher water availability has been previously reported (Van Leeuwen 2010).

Conclusion

The general assertion that cooler growing conditions produce Cabernet family winegrapes with higher IBMP concentrations appears to be an oversimplification: cooler pre-veraison temperatures are associated with less IBMP accumulation, but the IBMP degradation rate from 50 DAA to harvest was lower in the cooler season. As a result, IBMP concentrations at harvest were not significantly different between years, and concentrations in grapes and wines were comparable with those reported in warmer regions. Within each year, IBMP concentrations at 50 DAA were best predicted by factors associated with vine vigor, where vigorous vines accumulated higher IBMP preveraison. IBMP degradation postveraison was less successfully modeled, but was best predicted by factors associated with vine vigor, crop to vine size, and fruit maturity. The results of this study suggest that high IBMP concentrations at harvest are likely to occur at vigorous sites where warm preveraison temperatures are followed by inadequate fruit maturation. Also, factors that can contribute to variation within a given site (e.g. cluster light exposure) are not necessarily important for explaining the majority of variation across sites. In contrast to some previous studies, IBMP concentrations in wines were not correlated with herbaceous aromas, likely because the highest IBMP concentrations present were around the sensory threshold. In the wines under study, herbaceous aromas were best explained by vine water status and fruit maturity.

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CHAPTER 4

EFFECT OF SHOOT TIPPING ON 3-ISOBUTYL-2-METHOXYPYRAZINE CONCENTRATION IN CABERNET FRANC GRAPES

Abstract

A field study was conducted on *Vitis vinifera* L. cv. Cabernet franc to evaluate the effect of shoot tipping timing on 3-isobutyl-2-methoxypyrazine (IBMP) concentration in grapes berries. Treatments consisted of removing the tip of each shoot at either 10 days before anthesis, anthesis, or 10 days after anthesis. In both years, canopy density in fruiting zone and 30 cm above the fruiting zone was significantly increased by the 10 days before anthesis and anthesis tipping treatments. In 2009, the 10 days before anthesis and anthesis tipping treatments significantly increased (42.2 %) preveraison IBMP concentrations compared to the control. Shoot tipping did not impact preveraison IBMP concentrations in 2010 or concentrations at harvest in either year. In the warmer growing season (2010), average IBMP concentrations were higher at both 50 days after anthesis (~ 911%) and at harvest (~ 265%) compared to the cooler growing season (2009). In summary, shoot tipping did not impact the concentration of IBMP in mature grapes suggesting that it may not be an effective management strategy to reduce IBMP.

Introduction

The 3-akyl-2-methoxypyrazines (MPs) are a class of odorants produced by a wide range of horticultural crops (Murray and Whitfield 1975). In grapes and wine of several Bordeaux winegrape (*Vitis vinifera* L.) cultivars (e.g., Cabernet Sauvignon, Cabernet franc, Merlot, Carmenere, Sauvignon blanc), three MPs are commonly reported: 3-isobutyl-2-methoxypyrazine (IBMP), 3-isopropyl-2-methoxypyrazine (IPMP), and 3-secbutyl-2-methoxypyrazines (sBMP). Quantitatively, IBMP is the predominant grape MP, typically present in concentrations an order of magnitude higher than IPMP and sBMP (Alberts et al. 2009).

The sensory detection threshold of IBMP in red wine is reported as 10 to 15 pg/g (de Boubee et al. 2000, Kotseridis et al. 1998, Maga 1990). Several groups have reported a positive correlation between IBMP concentration in wine and the intensity of bell pepper aroma (Allen et al. 1991, de Boubee et al. 2000), although the relationship is less clear for concentrations around the detection threshold (Preston et al. 2008). IBMP masks fruity aromas (Hein et al. 2009) and the presence of herbaceous aromas are generally undesirable in red wine, thus recent studies have focused on developing management strategies to control MP levels.

In mature grape berries, IBMP is primarily (> 95%) located in the skins (de Boubee et al. 2002) and is ~ 70 % extracted with skin contact (Ryona et al. 2009). Consequently, the concentration of IBMP in finished red wine is largely dependent on the concentration in grapes at harvest. Because vinification and cellaring practices to remove MPs from musts or wine are ineffective or result in other nonselective changes (Blake et al. 2009, de Boubee 2003, Pickering et al. 2006), it has been proposed that management strategies to control MPs in wine should focus on reducing MPs in developing grape (Bogart and Bisson 2006).

IBMP accumulation occurs in grapes from set until approximately 0 to 14 days prior to veraison (de Boubee et al. 2000, Hashizume and Samuta 1999, Ryona et al. 2008, Sala et al. 2004). During fruit maturation, IBMP rapidly degrades to concentrations <10% of preveraison peak values. IBMP preveraison was reported to correlate with concentrations at harvest in the same growing region (Ryona et al. 2008), suggesting that accumulation may be an important determinant of final concentrations.

Grapes and wines produced in cool regions and in cooler years are reported to have higher MP concentrations (Allen et al. 1994, Belancic and Agosin 2007, Falcao et al. 2007, Kotseridis et al. 1998, Lacey et al. 1991). For example, Falcao et al. (2007) reported a negative correlation between minimum and maximum growing season temperature and IBMP concentration in Cabernet Sauvignon. Higher temperatures during the ripening period are thought to enhance MP degradation (Lacey et al. 1991) leading to lower concentrations at harvest, but the influence of preveraison temperatures is less clear.

Cluster light exposure is shown reduce IBMP in grapes at harvest (Allen et al. 1996, de Boubee et al. 2002, Maris et al. 1999, Noble et al. 1995, Ryona et al. 2008). Sun exposed clusters accumulate less IBMP than shaded clusters, and proportional differences persist until harvest. In contrast, cluster exposure does is not influence the rate of postveraison degradation (Ryona et al. 2008). Thus, management practices to improve cluster exposure (e.g. leaf removal) can reduce IBMP when imposed pre-veraison, but post-veraison treatments are ineffective (Scheiner et al. 2010).

Vigor inducing conditions such as high water availability and low bud number are associated with high MP concentrations. For example, Noble et al. (1995) observed higher preveraison IBMP concentrations in more vigorous sites and de Boubee et al. (2000) observed a lower IBMP degradation rate when vine growth was induced by late season rainfall. A negative correlation between number of buds left after winter pruning and IBMP in Cabernet Sauvignon wines was reported by Chapman et al. (2004). The authors attributed the difference in IBMP to vine yield, although vigor and cluster light exposure were not assessed.

Shoot tipping is a practice described as removing ≤ 8 cm from the shoot tip and shoot topping is described as removing ≥ 15 cm (Coombe 1959). When imposed around bloom, tipping and topping can improve fruit set resulting in higher yields (Coombe 1959, Coombe 1962, Collins and Dry 2009, Vasconcelos and Castognoli 2000). After shoots are tipped or topped, growth is delayed (Collins and Dry 2009, Wolf et al. 1986) before it is resumed by lateral shoots (Vasconcelos and Castognoli 2000, Wolf et al. 1986). The delay in growth from tipping and topping, can decrease pruning cane pruning weight (Collins and Dry 2009, Vasconcelos and Castognoli 2000) and leaf area (Vasconcelos and Castognoli 2000).

High vine vigor is associated with higher IBMP concentrations, thus management practices that reduce vigor may serve as a means to control IBMP in fruit. Although it is not established if IBMP is influenced by shoot growth rate (vigor) or vine capacity, shoot tipping is reported to delay shoot growth and leaf area. The objective of this study was to evaluate the impact of shoot tipping at three phenological stages on canopy density, yield, fruit maturity and 3-isobutyl-2-methoxypyrazine concentrations in Cabernet franc grapes.

Materials and Methods

Experimental design. A commercial vineyard in Hector, New York (42.28°N, 76.47°W; Finger Lakes AVA, Seneca Lake) was used in this study. The soil type was classified by the U.S.D.A. as Lansing series with a gravelly loam structure, well drained, and a depth of > 2 m. Vines were *Vitis vinifera* L. cv. Cabernet Franc cl. 312 grafted on SO4 rootstock and trained to a Scott Henry training system with two canes and two cordons. The upper canes were at 1.3 m and shoots were vertically positioned. The lower canes were at 1.0 m and shoots were positioned downward. Vineyard age was approximately 9 years. Vine management was performed according to the standard management practices for vinifera in the Finger Lakes region. The experimental design was a randomized complete block with four replications. The experimental plot consisted of four rows and each experimental unit consisted of eight contiguous vines in each row.

Treatments consisted of removing the tip (≤ 5 cm) of each shoot at either 10 days before anthesis (10 BA), anthesis (A), or 10 days after anthesis (10 DAA). Shoot tips were removed so that the resulting terminal leaf was ≤ 12 mm in diameter. The beginning of bloom was noted on 19 June 2009 and 13 June 2010. Time of anthesis was determined as the date on which 50 % capfall was visually estimated. In 2009, the calendar dates for the treatments were 9 June (10 BA), 19 June (A), and 29 June (10 DAA). In 2010, the calendar dates for the treatments were 3 June (10 BA), 13 June (A), and 23 June (10 DAA).

Climatic measurements. PAR, rainfall, and air temperature were monitored from 1 May through harvest with Hobo Micro Station Data Logger (Onset Computer Corporation, Bourne, MA) placed within 30 meters of the experimental plots. PAR, rainfall, and temperature were measured each minute and five minute averages were logged. Growing degree days (GDD) were determined as GDD = [(maximum daily temperature + minimum daily temperature) / 2] – 10 from 1 May to harvest.

Canopy characterization. Shoot diameters were measured midway between nodes 1 and 2 on 40 randomly selected shoots per experimental unit at 50 DAA and at harvest in both years with a Storm 3C301 Electronic Digital Caliper (Central Tools Incorporated, Cranston RI). The number of lateral shoots with ≥ 3 nodes were counted on 40 randomly selected shoots per experimental unit at 50 DAA and an average was recorded. Enhanced Point Quadrat Analysis (EPQA) was conducted at 10 cm intervals in the fruiting zone and at 30 cm above the upper tier of the fruiting zone (mid canopy) at 50 DAA and calibrated exposure maps were created (Meyers and Vanden Heuvel 2008). Fruiting zone insertions were made along each tier of the training system (i.e., Scott Henry). Measurements of photosynthetically active radiation (PAR, 400 - 700 nm) were taken in the fruiting zone with a AccuPAR LP-80 ceptometer (Decagon Devices, Cambridge, UK) on cloudless days between 10:30-3 pm. The probe was inserted parallel to the row in the interior of the canopy at the fruiting zone and mid canopy and the average of 4 readings was recorded. The number of count and non-count shoots was recorded at harvest.

Sampling and harvest. At 50 days after anthesis, 50 berries were collected at random from each experimental unit for IBMP quantification. At harvest, 200 berries were collected at random from each experimental unit for IBMP quantification and chemical analysis. The berry samples were placed in storage bags and immediately frozen with liquid N followed by stored at -23ºC until analyses were performed.

At harvest, fruit yield (measured with a hanging scale accurate to 0.01 kg; model SA3N340 Salter Brecknell, Fairmont, MN) and cluster counts were taken on each vine. Average cluster weight was determined by dividing crop weight by the number of clusters. Average fresh berry weight was determined by weighing the 200-berry harvest samples with a Setra SI410S balance (Setra Systems Inc., Boxborough, MA). In 2009 and 2010, the calendar dates for harvest were 25 October and 12 October. In 2010, average berry fresh weight was also determined at 50 DAA by weighing the 50-berry samples. During the winter, dormant cane pruning weight was recorded for each vine in 2009 and crop load was calculated as yield divided by pruning weight. Average cane weight was determined as total pruning weight divided by number of canes.

Berry Analysis for ºBrix, Titratable Acidity, and pH. A sub-sample of 100 mature berries was placed in a 250-mL beaker and heated to 65 ºC for one hour in a water bath to redissolve tartrates, pressed through cheesecloth with a pestle, and the juice was collected for analyses. Soluble solids (ºBrix) were measured using a digital refractometer (model 300017; SPER Scientific, Scottsdale, AZ) with temperature correction. TA and pH were measured with an automatic titrater (Titrino model 798, Metrohm, Riverview, FL). TA was measured with a 5.0-mL aliquot of juice by titration against 0.1 N NaOH to pH 8.2 and expressed as tartaric acid equivalents.

Berry Analysis for 3-Isobutyl-2-methoxypyrazine. IBMP analysis was conducted on 50-berry samples collected at 50 DAA and harvest. The extraction method was head space-solid phase micro extraction and quantification was performed by comprehensive two-dimensional gas chromatography time-of-flight mass spectrometry (GCxGC-TOF-MS) as described by (Ryona et al. 2009).

Statistical analysis. Statistical analysis were conducted with SAS statistical software (SAS Institue, Cary, NC). Data were subjected to PROC GLM and means were separated with Fischer's least significant difference (LSD) at the 5% significance level.

Results

3-Isobutyl-2-methoxypyrazine concentration. Shoot tipping impacted IBMP concentrations at 50 DAA in 2009 (Figure 1). IBMP ranged from 35.2 to 61.0 pg/g and the 10 DBA and AN treatments significantly increased IBMP concentrations by approximately 42% compared to the control. At harvest, IBMP concentrations ranged from 7.5 to 8.6 pg/g and there were no significant differences among treatments. Percent decrease in IBMP from 50 days after anthesis to harvest was significantly higher for all of the tipping treatments compared to the control. IBMP decreased by a treatment average of ~ 85 % compared to ~ 74 % for the control.

In 2010, IBMP concentrations were higher than in 2009, ranging from 460.6 to 524.9 and 17.9 to 24.2 pg/g at 50 DAA and harvest, respectively. There were no significant differences among treatments at either timing. Shoot tipping did not impact percent decrease in IBMP from 50 days after anthesis to harvest. On average, IBMP concentrations at harvest were 4.6 % of their respective preveraison (50 DAA) concentrations.

Canopy characteristics. In 2009, the number of laterals per shoot ranged from 2.51 to 5.26 (Table 1). The AN and 10 DAA treatments significantly increased the number of lateral shoots by 2.75 and 2.15, respectively. All shoot tipping treatments

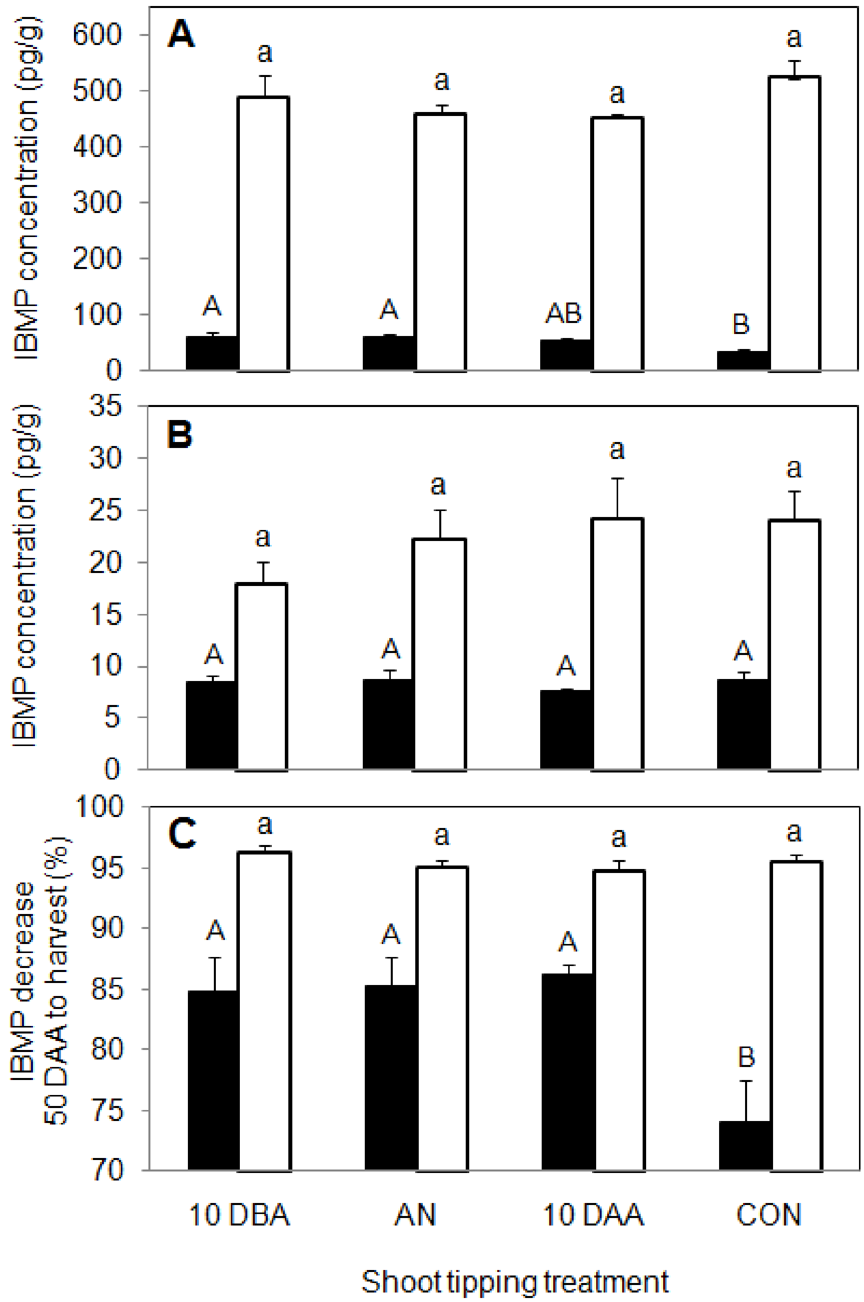

Figure 1 Impact of shoot tipping on IBMP concentration in Cabernet franc berries at (A) 50 days after anthesis (B) harvest and (C) percent decrease in IBMP concentration from 50 days after anthesis to harvest in 2009 (black bars) and 2010 (white bars). Each measurement represents the average of four field replicates. Values are mean ± SE. Means indicated by different letters are significantly different at $p \leq 0.05$, Fisher's LSD.

Table 1 Effect of shoot tipping on vine characteristics of Cabernet franc in 2009 and 2010.

Treatment	Shoot/vine	Laterals/shoot	Shoot diameter (mm) 50 DAA	Shoot diameter (mm) Harvest	Pruning weight (kg/vine)	Average cane weight (g)
2009						
10 DBA	36.5	4.43ab[b]	7.37b	7.34b	1.33	36.6
AN	34.3	5.26a	7.45b	7.38b	1.45	42.3
10 DAA	37.8	4.66a	7.68b	7.55b	1.40	37.1
CON	35.8	2.51b	8.02a	7.83a	1.57	43.9
Significance[a]	ns	*	*	*	ns	ns
2010						
10 DBA	32.5	5.02	-[c]	8.05	-	-
AN	32.9	5.91	-	7.56	-	-
10 DAA	26.9	4.36	-	7.90	-	-
CON	30.3	4.69	-	7.67	-	-
Significance	ns	ns	-	ns	-	-

[a]ns and * indicate not significant and statistically significant at the 0.05 level of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).
[c]Data not available.

significantly reduced shoot diameter at 50 DAA and at harvest by an average of 7 and 5 % respectively. Shoots per vine, pruning weight, and average cane weight ranged from 34.3 to 37.8, 1.33 to 1.57 kg, and 36.6 to 43.9 g, respectively, and there were no significant differences among treatments.

In 2010, the number of shoots per vine, laterals per shoot, and shoot diameter at harvest ranged from 26.9 to 32.9, 4.36 to 5.91, and 7.56 to 8.05, respectively, with no significant differences observed among treatments.

Canopy density, as measured by EPQA, was increased by all shoot tipping treatments in 2009 (Tables 2 and 3). Leaf layer number (LLN), percent interior leaves (PIL), occlusion layer number (OLN), leaf exposure layer (LEL), and canopy calibration coefficient (EP1) in the fruiting zone were significantly increased and leaf exposure flux availability (LEFA) was significantly reduced by all of the shoot tipping treatments (Table 2). The number of occlusions per insertion (OLN) increased by a treatment average of 0.73 occlusions as a result of tipping. LEL, and EP1 were increased by an average of 62, and 33 %, respectively and LEFA was reduced by an average of 5 %. There were no significant differences among treatments for percent gaps (PG), percent interior clusters (PIC), cluster exposure layer (CEL), cluster exposure flux availability (CEFA), and cluster exposure flux availability computed using the dynamic calibration model (CEFA*). In mid canopy, the 10 DBA and AN treatments significantly increased LLN, PIL, OLN, and LEL (Table 3). OLN was 3.63 and 3.51 for 10 DBA and AN treatments, respectively, compared to 2.59 for the control. The 10 DBA and AN treatments significantly reduced LEFA by an average of 9 % and the 10 DBA treatment significantly reduced LEFA*. Shoot tipping did not impact PG and EP1.

In 2010, the 10 DBA and AN treatments significantly increased LLN, PIL, PIC, OLN, and LEL and significantly reduced CEFA in the fruiting zone (Table 2). OLN and LEL were increased by an average of 0.85 occlusions and 0.15 layers over the control. CEFA was 27 and 31% for 10 DBA and AN treatments compared to 40% for the control. Shoot tipping did not impact PG, EP1, CEFA, LEFA, and LEFA* in the fruiting zone. In mid canopy, the 10 DBA and AN treatments significantly increased LLN, PIL, OLN, and LEL (Table 3). LLN was increased by an average of 0.74 leaf layers resulting in significant increases PIL, OLN, and LEL and significant decreases LEFA and PG. LEL and LEFA averaged 0.49 and 0.36 for the 10 DBA and AN treatments compared to 0.33 and 0.44 for the control.

Table 2 Effect of shoot tipping on canopy characteristics in the fruiting zone in Cabernet franc at 50 DAA in 2009 and 2010.

	EPQA metrics											
Treatment	**PG**	**LLN**	**PIL**	**PIC**	**OLN**	**CEL**	**LEL**	**EP1**	**CEFA**	**CEFA***	**LEFA**	**LEFA***
2009												
10 DBA	3.55	2.41a[b]	32.9a	62.4	3.07a	0.72	0.37ab	0.31a	0.38	0.15	0.45b	0.24b
AN	1.58	2.39a	34.0a	56.9	3.08a	0.61	0.39a	0.34a	0.41	0.22	0.46b	0.32ab
10 DAA	1.68	2.21a	27.8a	56.7	2.88a	0.62	0.31b	0.29a	0.41	0.25	0.48b	0.38b
CON	5.23	1.70b	20.3b	43.7	2.28b	0.44	0.22c	0.23b	0.43	0.31	0.52a	0.44a
Significance[a]	ns	**	**	ns	**	ns	**	*	ns	ns	*	*
2010												
10 DBA	0.76	2.71a	33.9a	79.0a	3.62a	0.95a	0.38a	0.31	0.27	0.08b	0.43	0.29
AN	0.54	2.52a	31.4a	73.9a	3.44a	0.85a	0.34a	0.31	0.31	0.12b	0.45	0.29
10 DAA	0.48	1.85b	23.6b	47.3b	2.82b	0.51b	0.24b	0.31	0.44	0.23a	0.51	0.32
CON	1.72	1.82b	20.7b	51.2b	2.68b	0.55b	0.21b	0.25	0.40	0.21a	0.50	0.35
Significance	ns	***	***	***	***	**	***	ns	ns	*	ns	ns

[a]ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).

Table 3 Effect of shoot tipping on canopy characteristics in mid canopy of Cabernet franc at 50 DAA in 2009 and 2010.

	EPQA metrics							
Treatment	**PG**	**LLN**	**PIL**	**OLN**	**LEL**	**EP1**	**LEFA**	**LEFA***
2009								
10 DBA	0.00	3.63a[b]	44.7a	3.63a	0.54a	0.16	0.33b	0.12b
AN	0.00	3.51a	43.6a	3.51a	0.50a	0.16	0.34b	0.29ab
10 DAA	0.63	2.78b	32.1b	2.78b	0.34b	0.14	0.41a	0.27ab
CON	1.80	2.59b	28.7b	2.59b	0.30b	0.11	0.42a	0.30a
Significance[a]	ns	**	**	**	**	ns	**	**
2010								
10 DBA	0.00b	3.74a	46.2a	3.74a	0.53a	0.22	0.34b	0.19
AN	0.00b	3.38a	40.3a	3.38a	0.44a	0.23	0.38b	0.22
10 DAA	1.74ab	2.74b	30.6b	2.74b	0.32b	0.23	0.45a	0.27
CON	3.32a	2.82b	32.3b	2.82b	0.33b	0.24	0.44a	0.26
Significance	*	**	**	**	**	ns	**	ns

[a]ns, *, and ** indicate not significant and statistically significant at the 0.05 and 0.01 levels of probability, respectively.

[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).

Yield components and juice chemistry. In 2009, the number of clusters per vine and vine yield ranged from 54.2 to 63.3 and 6.59 to 7.45 kg, respectively, and no significant differences observed among treatments (Table 4). The AN treatment

Table 4 Effect of shoot tipping on harvest parameters for Cabernet franc in 2009 and 2010.

Treatment	Clusters/vine	Yield/vine (kg)	Average cluster weight (g)	Average berry weight (g)		Crop load (yield/pruning weight)
				50DAA	Harvest	
2009						
10 DBA	56.1	6.59	118.0b	-[c]	1.47	4.95
AN	54.2	7.45	137.9a	-	1.54	5.23
10 DAA	60.8	7.43	121.1b	-	1.37	5.30
CON	63.3	7.45	117.7b	-	1.47	4.72
Significance[a]	ns	ns	*		ns	ns
2010						
10 DBA	70.4	13.70a[b]	196.4	0.84	88.0	-
AN	70.5	12.48a	177.1	0.82	98.2	-
10 DAA	58.1	10.51b	183.9	0.83	70.3	-
CON	67.1	11.45ab	169.9	0.84	81.3	-
Significance	ns	*	ns	ns	ns	-

[a]ns, and * indicate not significant and statistically significant at the 0.05 level of probability, respectively .
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).
[c]Data not available.

significantly increased cluster weight by 20.2 g and there were no differences among treatments for berry weight at harvest and crop load.

In 2010, yields were higher than the previous year, ranging from 10.51 to 13.70 kg per vine. The 10 DBA and AN treatments had significantly higher yields than the 10 DAA treatment, but were not significantly different from the control.

Clusters per vine and cluster weight ranged from 58.1 to 70.5 and 169.9 to 196.4 g with no significant differences among treatments. Shoot tipping did not impact fresh berry weight at 50 DAA or harvest.

In 2009, °Brix, TA, pH ranged from 20.1 to 20.7, 9.93 to 10.50, and 3.42 to 3.45, respectively, with no significant differences among treatments (Table 5). In 2010, °Brix was higher and TA was lower than the previous year. The range in °Brix,

Table 5 Effect of shoot tipping on berry chemistry and classic maturity indices for Cabernet franc in 2009 and 2010.

Treatment	TSS (°Brix)[b]	TA	pH	TSS (g/L)/TA	TSS (°Brix)*pH2
2009					
10 DBA	20.7	10.50	3.42	190.7	242
AN	20.1	10.21	3.43	190.7	236
10 DAA	20.3	10.00	3.45	200.3	241
CON	20.3	9.93	3.42	200.4	237
Significance[a]	ns	ns	ns	ns	ns
2010					
10 DBA	21.1	6.59	3.47	322.2	253.4
AN	21.9	6.55	3.47	335.1	263.3
10 DAA	21.8	6.71	3.43	325.5	256.8
CON	22.1	6.05	3.53	364.9	274.7
Significance	ns	ns	ns	ns	ns

[a]ns indicates not significant and statistically significant.
[b]TSS: total soluble solids.

TA, and pH was 21.1 to 22.1, 6.05 to 6.71, and 3.43 to 3.53. None of the shoot tipping treatments had a significant effect on juice chemistry.

Discussion

In contrast to reports that IBMP concentrations are higher in cooler regions or in cooler growing seasons (Allen et al. 1994, Belancic and Agosin 2007, Falcao et al. 2007, Lacey et al. 1991, Kotseridis et al. 1998), we observed higher IBMP at preveraison (~911.1 %) and harvest (264.7 %) in the warmer year (2010) of this study. Growing degree day accumulation (°C) from May 1 to harvest was 1535 in 2010 compared to 1300 in the previous year (Figure 2). IBMP did decrease more from 50 days after anthesis to harvest in the warmer season (2009 = 84.3 %; 2010 = 95.4 %), in concordance with Lacey et al. (1991), but greater accumulation resulted higher concentrations at harvest. Previous studies have generally focused on measuring IBMP

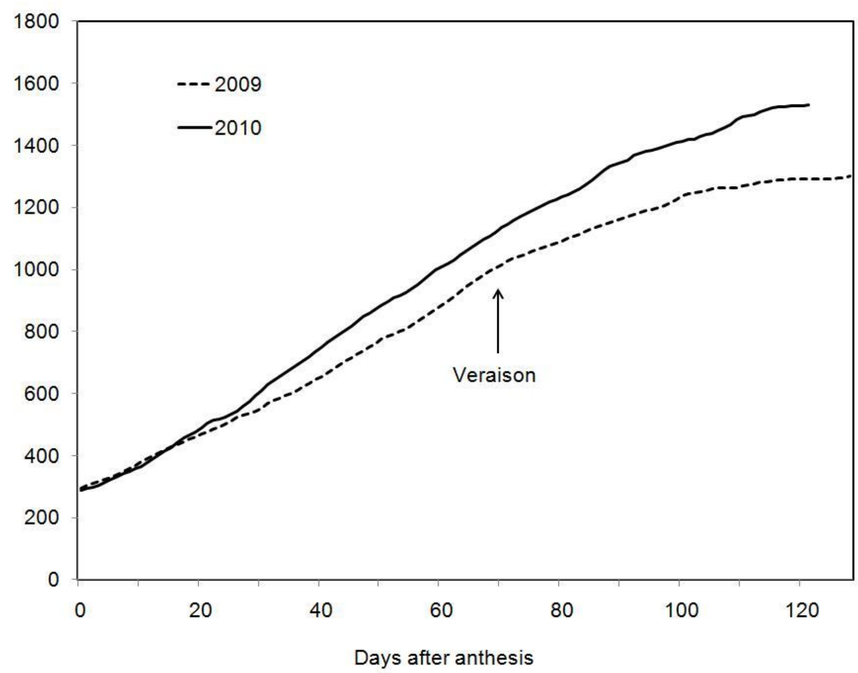

Figure 2. Growing degree days from anthesis to harvest in 2009 and 2010.

in berries after veraison, but in agreement in with Ryona et al. (2008), our results suggest that preveraison accumulation may be an important determinant of final IBMP concentrations. Although the mechanism behind the observed differences in IBMP is not clear, canopy characteristics and cluster exposure between years were not significantly different (data not shown). Thus, the difference between years cannot be solely attributed to vine growth and cluster light exposure.

Shoot tipping can increase lateral growth resulting in a denser canopy (Brown et al. 1988, Vasconcelos and Castognoli 2000, Wolf et al. 1986). In accordance, we observed a significant increase in lateral shoots in one year and increased canopy density at and above the fruiting zone in both years as a result of tipping. However, we did not observe an effect on pruning weight in 2009 as reported by others (Collins and Dry 2009, Vasconcelos and Castognoli 2000). Higher IBMP concentrations are associated with vigor inducing conditions (de Boubee et al. 2000, Noble et al. 1995), but it is unclear if accumulation or degradation is influenced by growth rate (e.g., vigor) or vine capacity. Following each tipping treatment, shoot growth was delayed, but one or two laterals became dominant and canopy fill was visually similar between treatments within three weeks of the tipping. Because fruit maturity was similar between treatments, we cannot establish that tipping had an impact on vine capacity. Although we observed a significant increase in IBMP from shoot tipping at 10 days before anthesis and anthesis in 2009, the effect did not persist until harvest. Because we quantified IBMP at two time points, we cannot determine how shoot tipping impacted IBMP evolution postveraison. In the tipped vines, IBMP decreased more from 50 day after anthesis to harvest, but is unknown if IBMP evolution is synchronous in vines with different growth characteristics and crop levels.

Conclusion

Shoot tipping 10 days before and at bloom increased canopy density and in one year, preveraison IBMP concentrations, but shoot tipping did not impact IBMP at harvest. In the warmer season, IBMP decreased more from 50 days after anthesis to harvest, but concentrations were higher at harvest as a result of greater accumulation. The results of this study suggest that tipping may not be an effective means of vigor control or IBMP reduction.

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CHAPTER 5

EFFECT OF CHLORMEQUAT RATE AND TIMING ON 3-ISOBUTYL-2-METHOXYPYRAZINE CONCENTRATIONS IN CABERNET FRANC GRAPES

Abstract

The effect of chlormequat [(2-chloroethyl)trimethyl-ammonium chloride] rate and timing on 3-isobutyl-2-methoxypyrazine (IBMP) concentration in grapes of potted Cabernet franc (*Vitis vinifera* L.) vines was evaluated. Chlormequat was applied as a spray at a rate of either 400 or 700 mg/L to the foliage at 7 days before anthesis, anthesis, or 30 days after anthesis, or to clusters at anthesis or 30 days after anthesis. Shoot internode length was reduced by the 7 days before anthesis and anthesis treatments, but there was not a consistent rate or timing effect on other vine characteristics (shoot length, laterals, vine weight). At 50 days after anthesis, IBMP concentration in berries (range = 28.0 to 90.8 pg/g) was increased by the 400 mg/L foliar treatment applied at 7 days before anthesis (~ 48%), the 800 mg/L foliar treatment applied at 7 days before anthesis (~ 67%), and the 800 m/L cluster treatment applied at 30 days after anthesis (~ 29%), but chlormequat did not impact IBMP concentration in berries at harvest (range = 17.9 to 20.1 pg/g). In summary, applications of chlormequat near bloom suppressed vine growth, but did not affect IBMP in grapes at harvest suggesting that it may not be an effective control strategy for IBMP.

Introduction

3-Isobutyl-2-methoxypyrazine (IBMP) is a potent odorant associated with herbaceous aromas of Cabernet franc and other Bordeaux winegrape (*Vitis vinifera* L.) cultivars. IBMP accumulates in grapes from berry set to 0 to 14 days prior to veraison, followed by a rapid decrease to harvest (de Boubee et al. 2000, Hashizume and Samuta 1999, Ryona et al. 2008, Sala et al. 2004). In general, IBMP concentrations in mature grapes and wine range from 0 to 50 pg/g (Allen and Lacey 1999).

The sensory detection threshold of IBMP in red wine is reported as 10 to 15 pg/g (de Boubee et al. 2000, Kotseridis et al. 1998, Maga 1990). At concentrations near the sensory detection threshold, IBMP may contribute positively to wine quality by adding complexity and in some cases, varietal character (Allen et al. 1991). At higher concentrations, IBMP is positively correlates with intensity of bell pepper aroma (Allen et al. 1991, de Boubee et al. 2000), although this is relationship may be less apparent at lower concentrations (Preston et al. 2008). Because herbaceous aromas are generally undesirable in red wine, there is interest in developing management practices to control IBMP.

In mature grape berries, IBMP is primarily (> 95%) located in the skins and is efficiently extracted with conventional red winemaking practices (de Boubee et al. 2002). Thus, the concentration of IBMP in grapes at harvest strongly correlates with concentration in resultant red wine (Ryona et al. 2009). Several groups evaluated various enological techniques to reduce IBMP in musts and wine and generally concluded that they were either ineffective or else resulted in other nonselective changes to the wine (Blake et al. 2009, de Boubee 2003, Marais 1998). It has thus been proposed that IBMP is most effectively controlled with viticultural practices that reduce concentrations in grapes (Bogart and Bisson 2006).

Because IBMP degrades with ripening (de Boubee et al. 2000, Hashizume and Samuta 1999, Ryona et al. 2008, Sala et al. 2004), fruit maturity at harvest is an important determinant of final concentration. A strong correlation between preveraison and harvest IBMP concentration was reported in grapes grown in the same region suggesting that accumulation may also influence final concentrations (Ryona et al. 2008).

Preveraison cluster light exposure can reduce IBMP accumulation leading to lower concentrations at harvest, but in contrast, postveraison cluster exposure does not influence the rate of postveraison degradation (Ryona et al. 2008). Thus, management practices that increase cluster exposure such as fruit zone leaf removal can reduce IBMP when imposed preveraison, but postveraison treatments are not efficacious (Scheiner et al. 2010).

Conditions that promote vigor such as high water availability and low bud number are associated with higher IBMP concentrations (Allen and Lacey 1993, de Boubee et al. 2000, Chapman et al. 2004, Noble et al. 1995), although the physiological mechanism is unknown. In Cabernet Sauvignon, bud number left after winter pruning was reported as negatively correlating with IBMP in resultant wines (Chapman et al. 2004). The authors attributed the observed correlation to the impact of pruning on yield, but bud number is inversely proportional to vine vigor (Winkler et al. 1974). Thus, the pruning treatments utilized are expected to have impacted vine vigor as well. Accordingly, Allen and Lacey (1993) observed an eight-fold difference in preveraison IBMP concentrations between Sauvignon blanc vines that were minimally pruned versus spur pruned. The minimally pruned vines were noted as having shorter shoots with higher cluster light exposure. As a consequence of high vigor, clusters may become shaded potentially confounding the vigor and light effect, but Ryona et al. (2008) noted that vigorous vines with similar levels of cluster exposure to less vigorous vines had higher IBMP concentrations suggesting the two factors independently influence IBMP.

Chlormequat [(2-Chloroethyl)-trimethylammonium] is a plant growth retardant that blocks gibberellic acid-3 (GA3) biosynthesis (Lang 1970). When applied to grapevines, chlormequat can reduce shoot elongation (Bahar et al. 2009, El-Morsy and Mansour 1998, Loreti and Natali 1974, Skene 1969) and total leaf area (Kumar et al. 1998). However, the impact of chlormequat on vine growth is dependent upon the phenological stage and rate of application. For example, Loreti and Natali (1974) reported reductions in final shoot length of up to 40 % after a single chlormequat application at 15 days before bloom, but postbloom applications had no effect. Bahar et al. (2009) observed a reduction in shoot length of 15% at a chlormequat rate of 100 mg/L compared to a reduction of 30% at 250 mg/L. Although chlormequat may reduce total leaf area (Kumar et al. 1998), treated grape leaves were reported to have higher chlorophyll contents and net photosynthesis (Nimmi 1979, Tezuka et al. 1980) suggesting that vigor suppression with chlormequat may not reduce vine capacity.

Vine vigor is associated with IBMP in grapes, but it has not been confirmed if vigor impacts IBMP accumulation and/or degradation or if there is an interaction with the phenological stage at which vine growth occurs. Chlormequat can reduce shoot vigor and the response can manipulated with the rate of application and phenological stage at which the application occurs. The objective of this study was to investigate the effect of rate and timing of chlormequat application on IBMP concentrations in Cabernet franc at preveraison and harvest.

Materials and Methods

Plant material. Thirty-six dormant *Vitis vinifera* L. cv. Cabernet franc cl. 1 grapevines grafted on 3309C rootstock were planted in 12 L nursery pots with PRO-MIX® on April 2008. The potted vines were placed on an outdoor gravel pad. Vines were maintained at two shoots and one cluster per vine. Drip irrigation was applied as needed and vines were fertilized with a balanced fertilizer (10-10-10) at 45-day intervals for a total of 4 times over the growing season. When shoots reached approximately 35 cm in length, they were affixed to bamboo stakes to minimize shading.

Experimental design. The experimental design was a randomized complete block with four replications. Each vine was considered an experimental unit. Treatments consisted of applying chlormequat (Cycocel®, OHP, Mainland, PA) to the foliage at 400 mg/L (a.i.) at either 7 days before anthesis (4 7DBA F) , anthesis (4 AN F), or 30 days after anthesis (4 30DAA F), or at 800 mg/L at either 7 days before anthesis (8 7DBA F) , anthesis (8 AN F), or 30 days after anthesis (8 30DAA F), to the cluster at 400 mg/L at 10 days after anthesis (4 AN C) or 30 days after anthesis (4 30DAA C), or at 800 mg/L at 10 days after anthesis (8 AN C) or 30 days after anthesis (8 30DAA C). Foliar and cluster chlormequat treatments were applied with a hand held spray bottle to the point of run-off. The calendar dates of the treatments were 7 days before anthesis (10 June), anthesis (25 June), and 30 days after anthesis (25 July).

Vine characterization. All vine measurements were taken at harvest (17 October). Shoot length and number of nodes per shoot were measured from node 1 to the apex of each shoot and a vine average was recorded. Internode length was determined by dividing shoot length by the number of nodes. Shoot diameters were measured midway between nodes 1 and 2 on each shoot with a Storm 3C301 Electronic Digital Caliper (Central Tools Incorporated, Cranston RI) and an average was recorded for each vine. The number of lateral shoots with ≥ 2 nodes were counted on each main shoot. Vines shoots were then severed below node 1 and all leaves were removed. The shoots were then dried in a drying oven at 80°C for a period of 5 days. Shoot dry weight was determined with a Setra SI410S balance (Setra Systems Inc., Boxborough, MA).

Sampling and harvest. At 50 days after anthesis (50 DAA), 5-berry samples were collected at random from each vine for IBMP quantification. At harvest, the remaining berries on each cluster were collected for IBMP quantification and chemical analysis. The berry samples were placed in storage bags and immediately frozen with liquid N followed by stored at -23ºC until analyses were performed.

Berry analysis for 3-isobutyl-2-methoxypyrazine. IBMP analysis was conducted on the 5-berry samples collected at 50 DAA, and a 15-berry sample collected at harvest. The extraction method was head space-solid phase micro extraction and quantification was performed by comprehensive two-dimensional gas chromatography time-of-flight mass spectrometry as described by (Ryona et al. 2009). Due to matrix inference, IBMP quantification was not possible for the 4-AN-F, 8-AN-F, 8-AN-C, 4-30DAA-F, 8-30DAA-F, AND 8-30DAA-C treatment harvest samples.

Berry Analysis for ºBrix, Titratable Acidity, and pH. The remaining harvest sample left after IBMP analysis was placed in a 250-mL beaker and heated to 65 ºC for one hour in a water bath to redissolve tartrates, pressed through cheesecloth with a pestle, and the juice was collected for analyses. Soluble solids (ºBrix) were measured using a digital refractometer (model 300017; SPER Scientific, Scottsdale, AZ) with temperature correction. TA and pH were measured with an automatic titrater (Titrino model 798, Metrohm, Riverview, FL). TA was measured with a 5.0-mL aliquot of juice by titration against 0.1 N NaOH to pH 8.2 and expressed as tartaric acid equivalents.

Statistical analysis. Statistical analysis was conducted using SAS statistical software (SAS Institue, Cary, NC). Data were subjected to PROC GLM and means were separated with Fisher's least significant difference (LSD) at the 5% significance level.

Results

3-Isobutyl-2-methoxypyrazine concentration. At 50 days after anthesis (preveraison), IBMP concentrations in berries ranged from 28.0 to 90.8 pg/g (Table 1). The 4-7DBA-F, 8-7DBA-F, and 8-30DAA-C treatments significantly increased (47, 67, and 30%, respectively) IBMP concentrations over the control. At harvest, the range in IBMP concentration was 17.9 to 20.1 pg/g and no significant differences were observed among treatments. The 4-7DBA-F, 8-7DBA-F treatments were 34 and 22% of their respective preveraison concentrations compared to 59% for the control.

Table 1 Effect of Chlormequat rate and timing on 3-isobutyl-2-methoxypyrazine (IBMP) concentrations in Cabernet franc berries.

	IBMP concentration (pg/g)	
Treatment	**50 DAA**	**Harvest**
4-7DBA-F	58.5b	19.7
8-7DBA-F	90.8a	20.1
4-AN-F	44.5bc	-[c]
8-AN-F	37.9c	-
8-AN-C	28.0c	-
4-30DAA-F	39.5bc	-
8-30DAA-F	34.7c	-
8-30DAA-C	42.6b	-
CON	30.3c	17.9
Significance	***	ns

[a]ns and *** indicate not significant and statistically significant at the 0.001 level of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).
[c]Data not available.

Vine characteristics. Shoot length ranged from 59.5 to 84.5 cm (Table 2). The 4-7DBA-F, 8-7DBA-F, 8-AN-F, and 4-30DAA-F chlormequat treatments significantly reduced shoot length by ~ 16, 11, 25, and 22 cm, respectively. Application of chlormequat did not impact the number of nodes per vine, but internode length was significantly reduced by the 4-7DBA-F, 8-7DBA-F, 4-AN-F, 8-AN-L, 8-AN-C. Shoot diameter ranged from 7.9 to 10.2 mm and the 8-30DAA-C treatment had a significantly lower shoot diameter than the 4-7DBA-F, 8-7DBA-F, and 8-AN-C treatments, but none of the chlormequat treatments were significantly different that the control. The number of laterals per vine (range = 3.6 to 11.4) was significantly increased by the 8-7DBA-F and 8-AN-F treatments by 4.3. Average shoot dry weight ranged from 275 to 511 g. The 4-7DBA-F, 4-AN-F, 8-AN-F, and 4-30DAA-F treatments significantly reduced shoot dry weight by 138, 236, 168, and 198 g, respectively, over the control, but only the 4-7DBA-F treatment significantly increased crop load.

Table 2 Effect of Chlormequat rate and timing on vine characteristics and crop load in Cabernet franc.

Treatment	Shoot length (cm)	Nodes	Internode length (cm)	Shoot diameter (mm)	Lateral shoots	Shoot dry weight (g)	Crop load (yield/pruning weight)
4-7DBA-F	68.3bc	35.5	1.92cd	10.2ab	8.9ac	373cd	0.58a
8-7DBA-F	74.0bc	39.4	1.88d	10.2a	11.4a	460ac	0.31bc
4-AN-F	73.8ad	37.8	1.96bd	8.9bd	3.6d	275d	0.32bc
8-AN-F	59.5d	31.1	1.93bd	8.5cd	11.4a	343bc	0.45ab
8-AN-C	78.3ab	35.3	2.26cd	9.5ac	9.4ab	470ac	0.35ac
4-30DAA-F	62.3cd	29.9	2.14ad	8.9ad	4.6cd	313cd	0.30bc
8-30DAA-F	80.3ab	33.1	2.50a	9.2ad	6.8bd	380ad	0.24bc
8-30DAA-C	83.8a	45.4	2.32ab	7.9d	10.0ab	508ab	0.14c
CON	84.5a	36.6	2.35a	9.3ad	7.1bd	511a	0.25bc
Significance	*	ns	*	*	*	**	*

[a]ns, *, and ** indicate not significant and statistically significant at the 0.05 and 0.01 levels of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).

Cluster weight and juice chemistry. There was a 3-fold difference between treatments in cluster weight (Table 3). The 4-7DBA-F treatment had a significantly higher cluster weight than the 4-AN-F, 8-30DAA-F, 4-30DAA-F, and 8-30DAA-C treatments, but none of the chlormequat treatment were significantly different than the control (Table 3). TSS (°Brix) and TA ranged from 15.4 to 18.4 and 8.6 to 11.8 with no significant differences among treatments. There were also no significant differences for pH, TSS/TA, and TSS*pH^2.

Table 3 Effect of Chlormequat rate and timing on cluster weight and juice chemistry in Cabernet franc.

Treatment	Cluster weight (g)	TSS (°Brix)[c]	TA	pH	TSS (°Brix)/TA	TSS (°Brix)*pH2
4-7DBA-F	215a[b]	17.5	10.8	3.48	162	211
8-7DBA-F	142ac	17.3	9.7	3.59	179	223
4-AN-F	88bc	18.4	11.8	3.47	155	221
8-AN-F	155ac	15.4	8.6	3.59	179	198
8-AN-C	165ab	16.3	9.6	3.63	170	214
4-30DAA-F	95bc	17.0	10.2	3.60	167	220
8-30DAA-F	93bc	17.5	10.8	3.52	163	217
8-30DAA-C	69c	18.1	10.2	3.53	177	225
CON	130ac	16.5	11.7	3.53	141	205
Significance[a]	*	ns	ns	ns	ns	ns

[a]ns and * indicate not significant and statistically significant at the 0.05 level of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).
[c]TSS: total soluble solids.

Discussion

Higher IBMP concentrations are associated with vigor inducing conditions such as high water availability and low bud number, although the specific relationship with vine vigor (i.e., growth rate) or vine capacity is not well defined. The earliest chlormequat treatments (7 days before anthesis) significantly reduced shoot vigor, but had higher preveraison IBMP concentrations. Because the treatments did not impact the number of nodes per shoot we cannot confirm that suppressing vigor with chlormequat reduced the actual photosynthetic capacity of the vines. Several groups reported increased leaf chlorophyll content and net photosynthesis (Tezuka et al. 1980, Niimi 1979) in chlormequat treated grape leaves, thus it may be possible that IBMP increased as a result of a higher photosynthetic capacity. In concordance, the 800 mg/L chlormequat treatment applied at 7 days before anthesis had a significantly higher number of lateral shoots and a 67% higher preveraison IBMP concentration than the untreated vines.

An alternative explanation is that 50 days after anthesis sample timing did not correspond to the actual peak in IBMP concentration in all of the treatments. Previous research indicates that IBMP peaks in concentration at 0 to 14 days prior to veraison (de Boubee et al. 2000, Hashizume and Samuta 1999, Ryona et al. 2008, Sala et al. 2004), but the specific timing with respect to phenological stage is not well defined nor is synchronicity between vines. Vigor (Carbonneau 1996) and crop load (vine capacity : crop) (Jackson and Lombard 1993) can influence the rate and timing of fruit maturation and although on a percentage basis, IBMP decreased more from 50 days after anthesis to harvest in the two earliest chlormequat treatments (data not shown), the actual rate of postveraison degradation cannot be determined. Belancic and Agosin (2008) reported that IBMP concentrations plateaued in Carmenere before the end of sugar maturity. Thus, less mature fruit may continue to degrade IBMP and reach a similar concentration as more advanced fruit with additional hangtime. However, we did not observe any differences in fruit maturity to indicate that chlormequat impacted maturation.

Conclusion

The effect of chlormequat on vine growth was inconsistent. Several treatments reduced shoot growth, but there was not a clear rate or timing response. Preveraison IBMP concentrations in berries were higher in the earliest treatment timing, but the effect did not persist until harvest. Our results suggest that vigor suppression with chlormequat may not be an effective means of controlling IBMP concentrations.

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CHAPTER 6

EVALUATION OF 3-ISOBUTYL-2-METHOXYPYRAZINE CONCENTRATIONS IN GRAPES OF CABERNET FRANC CLONES

Abstract

A field study was conducted on *Vitis vinifera* L. cv. Cabernet franc to evaluate the influence of clone on 3-isobutyl-2-methoxypyrazine (IBMP) concentrations in grapes at preveraison and harvest. At site 1, vines were clone 1, 214, 327, and 312 and at site 2, vines were clone 214, 327, and 312. At 50 days after anthesis, there were significant differences in IBMP concentration between clones at site 1. IBMP concentration (range = 35.2 to 101.7 pg/g) was highest in clone 327 followed by clone 1, 214, and 312. Vine and canopy characteristics varied by clone at site 1 and the concentration of IBMP at 50 days after anthesis negatively correlated (R^2 = 0.88) with crop load. At site 2, there were no differences between clones in IBMP concentration at 50 days after anthesis and there were no differences between clones at either site for IBMP at harvest. In summary, the clones under study did not possess inherent characteristics that consistently resulted in variability in IBMP concentration.

Introduction

The 3-akyl-2-methoxypyrazines (MPs) are a class of odorants important to the sensory properties of several Bordeaux winegrape (*Vitis vinifera* L.) cultivars. In wine, MPs are described as having musty, herbaceous, and unripe aromas (Maga 1990). Quantitatively, 3-isobutyl-2-methoxypyrazine (IBMP) is the predominant MP, typically present in concentrations an order of magnitude higher than the other grape derived MPs (3-isopropyl-2-methoxypyrazine and 3-secbutyl-2-methoxypyrazine) (Alberts et al. 2009).

In red wine, the sensory detection threshold of IBMP is reported as 10 to 15 pg/g (de Boubee et al. 2000, Kotseridis et al. 1998, Maga 1990) and several groups reported a correlation between IBMP concentration in wine and intensity of bell pepper aroma (Allen et al. 1991, de Boubee et al. 2000). Although this relationship has not been universally observed (Preston et al. 2008), herbaceous aromas in red wine are generally undesirable. Consequently, there is interest in developing methods to control IBMP.

IBMP is predominantly located (> 95%) in the skins of mature grapes and is quantitatively extracted with skin fermentation (de Boubee et al. 2002). Thus, the concentration in finished red wine is largely dependent upon the concentration in grapes at harvest. Several studies evaluated vinification and cellaring techniques to remove MPs from musts or wine (de Boubee 2003, de Boubee 2003, Blake et al. 2009, Marais 1998, Pickering et al. 2006) and generally concluded that remediation of MPs was either ineffective or else resulted in nonselective changes to wine. Thus, management practices that reduce MP in grapes have been proposed as the most effective means of controlling MPs in wine (Bogart and Bisson 2006).

In grape berries, IBMP evolution follows a pattern of preveraison accumulation and postveraison degradation. IBMP accumulation begins around berry set and a peak in concentration occurs 0 to 14 days prior to veraison, followed by a rapid decline over maturation (de Boubee et al. 2000, Hashizume and Samuta 1999, Ryona et al. 2008, Sala et al. 2004). Although grape maturity level at harvest is an important determinant of final IBMP concentrations (Bogart and Bisson 2006), Ryona et al. (2008) reported a strong correlation between IBMP concentrations at preveraison and harvest suggesting accumulation may also be important.

IBMP concentrations between and within regions are routinely reported to exceed an order of magnitude (Ryona et al. 2008, Allen et al. 1994, Noble et al. 1995) and much of the observed variability has been attributed to environmental conditions and physiological factors. Higher MP concentrations are commonly reported in cooler growing regions and cooler seasons (Kotseridis et al. 1998, Allen et al. 1994, Lacey et al. 1991, Belancic and Agosin 2007, Falcao et al. 2007) and it is thought that warmer temperatures during the ripening period enhance MP degradation (Lacey et al. 1991). Preveraison cluster light exposure can reduce IBMP accumulation and differences between exposed and shaded clusters persist until harvest (Ryona et al. 2008). In contrast, postveraison cluster exposure does not influence the rate of IBMP degradation. Thus, viticultural practices that improve cluster light exposure such as basal leaf removal can reduce IBMP when imposed preveraison, but postveraison treatments are ineffective (Scheiner et al. 2010). Conditions that promote vine vigor such as high water availability and low bud number are associated with higher IBMP concentrations (de Boubee et al. 2000, Noble et al. 1995, Noble et al. 1995, Chapman et al. 2004), although the relationship has not been clearly defined. Higher preveraison IBMP concentrations were observed in more vigorous sites (Noble et al. 1995) and last season vine growth induced by high rainfall was reported to reduce IBMP degradation (de Boubee et al. 2000) suggesting that vigor may influence both IBMP accumulation and degradation.

Several studies reported large differences in IBMP concentration between *Vitis vinifera* clones and generally concluded that clonal selection may be a useful tool for managing IBMP (Battistutta et al. 2000, Belancic and Agosin 2008, Kotseridis et al. 1998). Kotseridis et al. (1998) evaluated four Merlot clones over a two year period and reported a two-fold difference in IBMP concentration in wine, although relative differences were not consistent from year to year. Single season studies were conducted on clones of Carmenere (Belancic and Agosin 2008) and Cabernet Sauvignon (Battistutta et al. 2000) and > three-fold differences were observed between clones.

We are unaware of any literature that evaluated IBMP concentrations in clones of Cabernet franc. Previous research suggests that clonal selection is a viable management strategy to control IBMP, but the variability observed was not adequately explained by inherent clonal characteristics that could be utilized for clonal selection. The objective of this study was to evaluate the influence of clone on IBMP concentrations in Cabernet franc grapes at preveraison and harvest. Vine and canopy measurements were taken to determine if the clones possessed characteristics that confer utility for IBMP management.

Materials and Methods

Experimental design. Two commercial vineyards in Hector, New York (42.28°N, 76.47°W; Finger Lakes AVA, Seneca Lake) were used in this study. The soil types were classified by the U.S.D.A. as Lansing series with a gravelly loam structure, well drained, and a depth of > 2 m (site 1) and Conesus series with a silt loam structure, moderately drained, and a depth of > 2 m (site 2). At site 1, vines were *Vitis vinifera* L. cv. Cabernet Franc cl. 1, 214, 312, and 327 grafted on SO4 rootstock. At site 2, vines were *Vitis vinifera* L. cv. Cabernet Franc cl. 214, 312, and 327 grafted on 3309C rootstock. At both sites, vines were trained to a Scott Henry training system with two canes and two cordons. The upper canes were at 1.3 m and shoots were vertically positioned. The lower canes were at 1.0 m and shoots were positioned downward. Vine management was performed according to the standard management practices for vinifera in the Finger Lakes region. Experimental plots consisted of four rows of each clone and each experimental unit consisted of 4 contiguous vines in each row. At each site, the experimental units were located within < 100 m of each other.

Vine/canopy characterization. At 50 days after anthesis, measurements of shoot diameter and enhanced point quadrat analysis (EPQA) were conducted. Shoot diameters were measured midway between nodes 1 and 2 on 40 randomly selected shoots per experimental unit at 50 DAA and at harvest in both years with a Storm 3C301 Electronic Digital Caliper (Central Tools Incorporated, Cranston RI). EPQA was conducted at 10 cm intervals in the fruiting zone and 30 cm above the fruiting zone (mid canopy) and calibrated exposure maps were created (Meyers and J.E. Vanden Heuvel 2008). Measurements of photosynthetically active radiation (PAR, 400 - 700 nm) were taken in the fruiting zone with a AccuPAR LP-80 ceptometer (Decagon Devices, Cambridge, UK) on cloudless days between 10:30-3 pm. The probe was inserted parallel to the row in the interior of the canopy at the fruiting zone and mid canopy and the average of 4 readings was recorded. At harvest, the number of count shoots was recorded for each vine. The beginning of bloom was noted on 19 June. Time of anthesis was determined as the date on which 50 % capfall was visually estimated. The calendar dates for fifty days after anthesis (50 DAA) and harvest were 3 August and 22 October, respectively.

Sampling and harvest. At 50 days after anthesis, 50 berries were collected at random from each experimental unit for IBMP quantification. At harvest, 200 berries were collected at random from each experimental unit for IBMP quantification and chemical analysis. The berry samples were placed in storage bags and immediately frozen with liquid N followed by stored at -23ºC until analyses were performed.

At harvest, yield (measured with a hanging scale accurate to 0.01 kg; model SA3N340 Salter Brecknell, Fairmont, MN) and cluster counts were taken on each vine. Cluster weight was calculated by dividing the yield by the number of clusters. Average fresh berry weight was determined by weighing the 200-berry harvest samples with a Setra SI410S balance (Setra Systems Inc., Boxborough, MA).

Berry Analysis for ºBrix, Titratable Acidity, and pH. A sub-sample of 150 mature berries was placed in a 250-mL beaker and heated to 65 ºC for one hour in a water bath to redissolve tartrates, pressed through cheesecloth with a pestle, and the juice was collected for analyses. Soluble solids (ºBrix) were measured using a digital refractometer (model 300017; SPER Scientific, Scottsdale, AZ) with temperature correction. TA and pH were measured with an automatic titrater (Titrino model 798, Metrohm, Riverview, FL). TA was measured with a 5.0-mL aliquot of juice by titration against 0.1 N NaOH to pH 8.2 and expressed as tartaric acid equivalents.

Berry Analysis for 3-Isobutyl-2-methoxypyrazine. IBMP analysis was conducted on 50-berry samples collected at 50 DAA and harvest. Head space-solid phase micro extraction (HS-SPME) was the extraction method and quantification was performed by comprehensive two-dimensional gas chromatography time-of-flight mass spectrometry (GCxGC-TOF-MS as described by (Ryona et al. 2009).

Statistical analysis. Statistical analysis was conducted with SAS statistical software (SAS® Institute, Cary, NC). Data were subjected to the Proc GLM procedure and means were separated using Fisher's protected least significant difference (LSD) at the 5% level. Prior to analysis of variance (ANOVA), Levene's test was conducted to test homogeneity of variance. Those data failing that test were transformed (log transformation) and retested for homogeneity of variance prior to ANOVA.

Results

3-Isobutyl-2-methoxypyrazine concentration. There were significant differences between clones at site 1 for IBMP concentration at 50 days after anthesis (Figure 1A). IBMP ranged from 35.2 to 101.7 pg/g and clone 327 had a significantly higher (62%) IBMP concentration than the other clones. Clone 1 and 214 were not significantly different and clone 312 had a significantly lower (~242%) concentration than the other clones. At site 2, there were no significant differences among clones for IBMP concentration at 50 days after anthesis (range = 77.1 to 98.2 pg/g). At harvest, IBMP concentrations ranged from 7.5 to 9.4 pg/g and 8.4 to 10.5 pg/g at sites 1 and 2, respectively, and there were no significant differences among clones at either site (Figure 1B). On average, IBMP concentrations at sites 1 and 2 were 11.5 and 11.1%, respectively, of the respective concentrations at 50 days after anthesis.

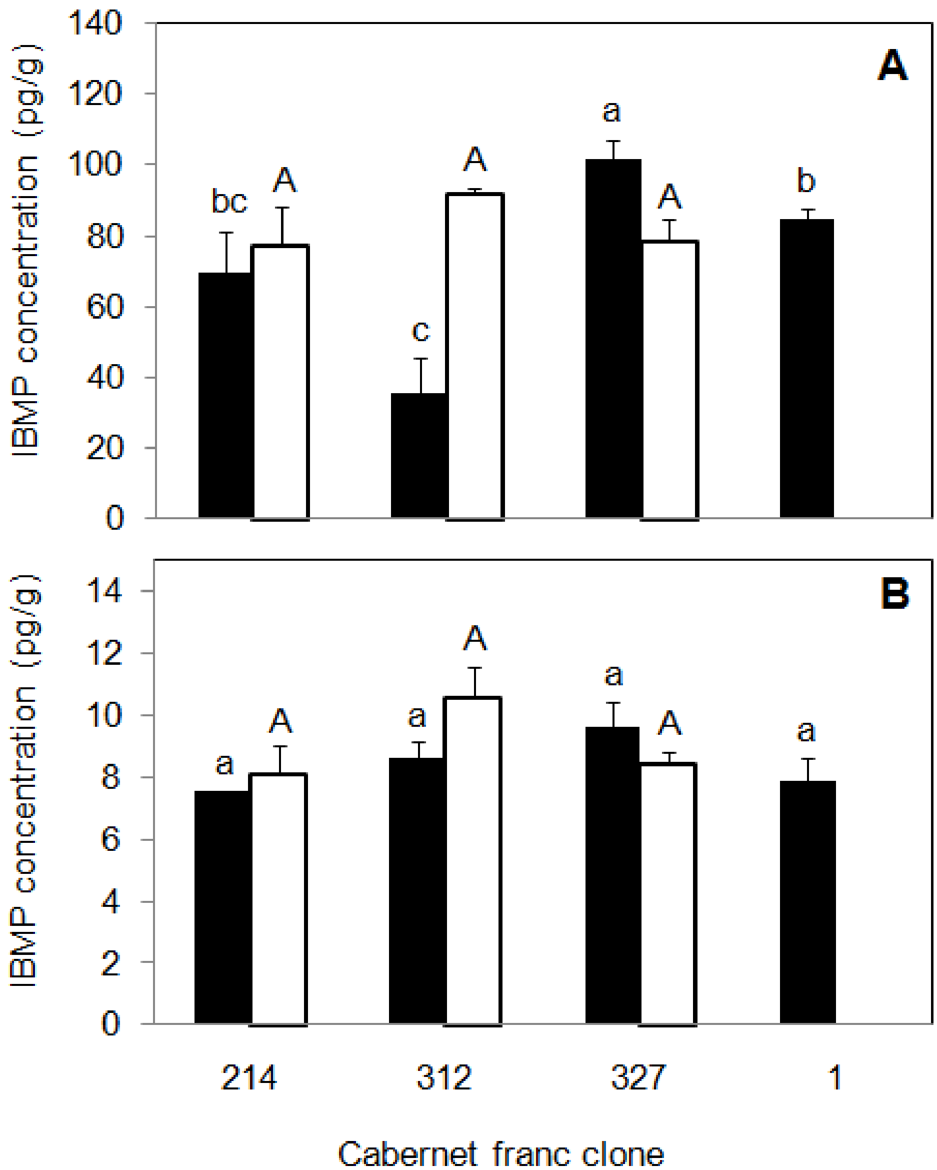

Figure 1 IBMP concentration in Cabernet franc clones at **(A)** 50 days after anthesis and **(B)** harvest at site 1 (black bars) and 2 (white bars). Values are means are ± SE. Means indicated by different letters are significantly different at $p < 0.05$, Fisher's LSD.

Vine characterization. At site 1, vine characteristics varied by clone (Table 1). Clone 312 had a significantly higher number of shoot per vine than the other clones by an average of 6 shoots per vine. At 50 days after anthesis, clone

Table 1 Vine characteristics for Cabernet franc clones at Sites 1 and 2.

Clone	Shoot/vine	Shoot diameter (mm) 50 DAA	Shoot diameter (mm) Harvest	Pruning weight (kg/vine)	Average cane weight (g)
Site 1					
1	32.8b	7.81bc	7.47b	2.2a	66.3ab
214	28.9b	8.64a	8.27a	2.0ab	69.7a
312	37.7a	8.00b	7.83ab	1.5c	39.3c
327	31.8b	7.61c	7.96a	1.9b	58.8b
Significance[a]	**	***	*	***	***
Site 2					
214	33.7	8.71a	8.23a	2.0a	58.5a
312	35.9	7.83b	7.76b	1.6b	43.3b
327	32.8	7.55b	7.69b	1.2b	35.0b
Significance	ns	***	*	*	*

[a]ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).

214 had the highest shoot diameter, followed by clone 312 and 214, and clone 327. However, the relative differences were not observed at harvest. Clone 214 had the highest shoot diameter followed by clones 327, 312, and 1. Although clone 312 had a greater number of shoots per vine than the other clones, it had the lowest pruning weight and average cane weight. Clone 1 and clone 214 had significantly higher pruning weights (range = 1.5 to 2.2 kg) than the other clones.

At site 2, clone 214 produced larger shoots than clones 312 and 327. Shoot diameters ranged from 7.55 to 8.71 and 7.69 to 8.23 at 50 days after anthesis and at harvest, respectively, and clone 214 had significantly higher shoot diameters than the other clones at both measurement timings. Similarly, clone 214 had a significantly higher pruning weight (range = 1.2 to 2.0) and average cane weight (range = 35.0 to 58.5) than clone 312 and 327.

Canopy characterization. At 50 days after anthesis, significant differences were observed between clones for canopy density at both sites (Table 2 and 3). At site 1, occlusion layer number (OLN) in the fruiting zone ranged from 2.03 to 2.65 and clone 327 had fewer occlusions per insertion than clone 1 and 214 (Table 2). The difference in OLN was reflected by cluster exposure layer (CEL) and cluster exposure flux availability (CEFA). Clone 327 had a lower CEL and higher CEFA than the other clones, but there were no significant differences for leaf exposure layer (LEL).

Mid canopy density was similar between the clones at site 1 (Table 3). OLN ranged from 2.26 to 2.65 and there were no significant differences among clones for OLN in addition to percent gaps (PG), leaf layer number (LLN), percent interior leaves (PIL), OLN, LEL, and leaf exposure flux availability computed using the dynamic canopy calibration model (LEFA*).

At site 2, clone 327 had a denser canopy than clone 312 and 214 (Table 2 and 3). OLN in the fruiting zone ranged from 2.26 to 3.17 and clone 327 had a significantly higher OLN, CEL, and LEL than the other clones. Clone 312 had more cluster light exposure than the other clones. CEFA ranged from 0.37 to 0.56 and clone 312 had ~ 44% higher CEFA than the other clones.

In mid canopy, OLN (range = 2.33 to 3.47) was highest in clone 327 followed by clone 214 and 312 (Table 3). LEL ranged from 0.23 to 0.52 and clone 327 was had a ~ 47% higher LEL than the other clones. Consequently, clone 327 had a significantly lower LEFA than clone 214 and 312.

Yield components. There was a wide range in yield per vine (4.60 to 8.44) at sight 1, but there were no significant differences among clones (Table 4). Clone 312 had a significantly higher number of clusters per vine than clone 327, but neither were significantly different from clones 1 and 214. Berry weights ranged from 1.35 to 1.49 and clone 327 had significantly smaller berries than clone 312 and 1. The range in clone 327 had a significantly higher cropload than clone 214 while clone 312 was not statistically different from the other clones.

Juice chemistry and maturity indices. Total soluble solids ranged from 19.8 to 21.3 at site 1 (Table 5). Clone 214 had significantly higher total soluble solids than clone 312 and 1, but was not significantly different from clone 327. There were no significant differences among clones for the other juice chemistry parameters (titratable acidity and pH) or maturity indices (°Brix / titratable acidity and °Brix * pH^2).

At site 2, total soluble solids and titratable acidity ranged from 20.7 to 21.3 and 10.4 to 11.3 with no significant differences among clones. However, there were significant differences observed for total soluble solids / titratable acidity. Clone 312 was significantly higher than clone 327 and 214 by an average of ~ 8%. No significant differences among treatments were observed for pH and total soluble solids * pH^2.

Table 2 Canopy characteristics in the fruiting zone of Cabernet franc clones measured with EPQA at 50 DAA at site 1 and 2.

	EPQA metric											
Clone	**PG**	**LLN**	**PIL**	**PIC**	**OLN**	**CEL**	**LEL**	**EP1**	**CEFA**	**CEFA***	**LEFA**	**LEFA***
Site 1												
1	4.85	1.93a	24.9	47.1a	2.55a	0.49a	0.27	0.22	0.42b	0.29b	0.47	0.38
214	2.60	1.98a	23.6	53.2a	2.65a	0.58a	0.25	0.30	0.42b	0.26b	0.50	0.40
312	4.84	1.71ab	20.3	44.8a	2.30ab	0.45a	0.22	0.23	0.43b	0.31ab	0.52	0.45
327	5.93	1.33b	14.1	27.6b	2.03b	0.28b	0.14	0.31	0.59a	0.38a	0.59	0.38
Significance	ns	*	ns	**	*	*	ns	ns	*	ns	ns	ns
Site 2												
214	2.54	1.96ab	21.3b	54.5b	2.57b	0.59b	0.22b	0.36	0.46b	0.24a	0.55b	0.38a
312	4.08	1.52bc	14.9b	40.9b	2.26b	0.42c	0.15b	0.37	0.56a	0.29a	0.60a	0.40a
327	0.42	2.43ca	31.8a	69.6a	3.17a	0.85a	0.36a	0.37	0.37b	0.10b	0.48c	0.26b
Significance	ns	**	**	**	**	**	**	ns	*	*	***	**

[a]ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).

Table 3 Canopy characteristics in mid canopy of Cabernet franc clones measured with EPQA at 50 DAA at site 1 and 2.

	EPQA metric							
Clone	**PG**	**LLN**	**PIL**	**OLN**	**LEL**	**EP1**	**LEFA**	**LEFA***
Site 1								
1	3.18	2.38	23.0	2.38	0.25	0.10b	0.46ab	0.31
214	3.74	2.26	21.6	2.26	0.22	0.12b	0.48a	0.46
312	2.40	2.54	28.2	2.54	0.29	0.12b	0.43b	0.38
327	4.17	2.65	29.9	2.65	0.31	0.17a	0.43b	0.32
Significance	ns	ns	ns	ns	ns	*	*	ns
Site 2								
214	2.51a	2.64b	29.3b	2.64b	0.32b	0.32	0.50a	0.28
312	2.74a	2.33c	23.2c	2.33c	0.23b	0.20	0.50a	0.26
327	0.00b	3.47a	43.3a	3.47a	0.52a	0.22	0.36b	0.22
Significance	*	***	***	***	**	ns	*	ns

[a]ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).

Table 4 Yield components for Cabernet franc clones at Sites 1 and 2.

Clone	Clusters/vine	Yield/vine (kg)	Average cluster weight (g)	Average berry weight (g)	Crop load (yield/pruning weight)
Site 1					
1	55.3ab	8.44	153.2	1.49a	3.88ab
214	50.8ab	7.04	138.6	1.37bc	3.50b
312	62.4a	8.06	129.4	1.47ab	5.44a
327	31.0b	4.60	148.9	1.35c	2.46b
Significance[a]	*	ns	ns	*	**
Site 2					
214	47.1	5.61	119.3	1.33	2.90b
312	50.6	5.51	108.2	1.23	3.56ab
327	42.6	4.77	112.1	1.21	4.20a
Significance	ns	ns	ns	ns	*

[a]ns, *, and ** indicate not significant and statistically significant at the 0.05 and 0.01 levels of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).

Table 5 Berry chemistry and classic maturity indices for Cabernet franc clones at Sites 1 and 2.

Clone	TSS (°Brix)	TA	pH	TSS (g/L)/TA	TSS (°Brix)*pH2
Site 1					
1	19.8c[b]	10.7	3.40	181	228
214	21.3a	10.6	3.39	200	245
312	20.3bc	9.9	3.42	200	237
327	21.2ab	10.4	3.44	201	251
Significance[a]	*	ns	ns	ns	ns
Site 2					
214	20.8	10.8	3.40	190b	240
312	21.3	10.4	3.44	201a	253
327	20.7	11.3	3.40	180b	239
Significance	ns	ns	ns	***	ns

[a]ns and *** indicate not significant and statistically significant at the 0.001 level of probability, respectively.
[b]Means followed by different letters are significantly different at the 95% level (Fisher's LSD).

Discussion

Previous studies reported > two-fold differences in IBMP concentration in wines from clones of Merlot (Kotseridis et al. 1998), Carmenere (Belancic and Agosin 2008), and Cabernet Sauvignon (Battistutta et al. 2000), but we did not observe any differences between clones at harvest. At preveraison, there was a > 3-fold difference in IBMP at one site and the variability may be explained by differences in vine characteristics and canopy microclimate, but there is no clear indication to confirm a specific factor. The highest and lowest IBMP concentrations were observed in clone 327 and clone 312 and in comparison, the two had similar characteristics with respect to vigor. Clone 327 had more exposed fruit than the other clones, but previous research indicates that cluster exposure reduces IBMP accumulation (Ryona et al. 2008), thus contradicting our observation. However, it is unclear if cluster exposure can result in a temporal shift in IBMP evolution. Thus, it may be possible that the 50 days after anthesis sample timing did not correspond with the peak in IBMP concentration across clones as a result of differences in cluster light exposure.

An alternative explanation is that the variability cropload (yield / pruning) may have accounted for the differences between the two clones. The association of IBMP and vigor has generally been related to vine growth, but it would be expected that high and low vigor vines would have distinct crop loads. Chapman et al. (2004) reported a negative correlation between number of buds per vine and IBMP concentration and although the relationship was attributed to yield, the capacity of a vine to ripen the crop is an important determinant of fruit maturation and characteristics at harvest (Jackson and Lombard 1993). We observed a strong correlation ($R^2 = 0.88$) between IBMP concentration at 50 days after anthesis and crop load (Figure 2), but not for vine yield. It may be possible that the clones with the lowest croploads were more vigorous resulting in higher IBMP accumulation. Although the decrease in IBMP was greater in the clones that accumulated more IBMP, we did not observe sufficient differences in fruit maturity to suggest that fruit matured faster in these clones. However, IBMP degradation may be decoupled from sugar accumulation and malic acid degradation.

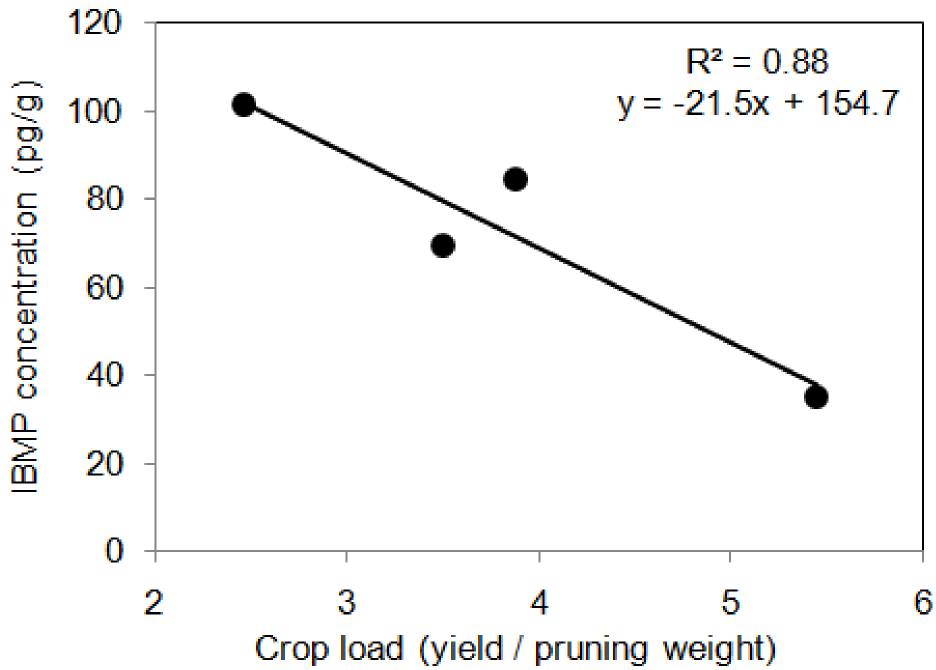

Figure 2 Correlation between crop load and IBMP concentration at 50 days after anthesis in Cabernet franc clones at site 1.

The concentrations of IBMP observed in the clones at harvest were at or just below the sensory detection threshold for red wine. Previous research indicates that approximately 70% of IBMP is extracted during skin fermentation (Ryona et al. 2009), thus concentrations in wine would be lower than that observed in berries.

Consequently, none of the clones under study had IBMP concentrations that would result in herbaceous wine aromas.

Conclusion

Differences in vine and canopy characteristics were observed between clones, but they were not consistent across sites. At one site, preveraison IBMP concentration were significantly different between clones. At harvest, IBMP concentrations were similar for all clones suggesting that the clones under study did not possess unique characteristics that could be exploited for IBMP control.

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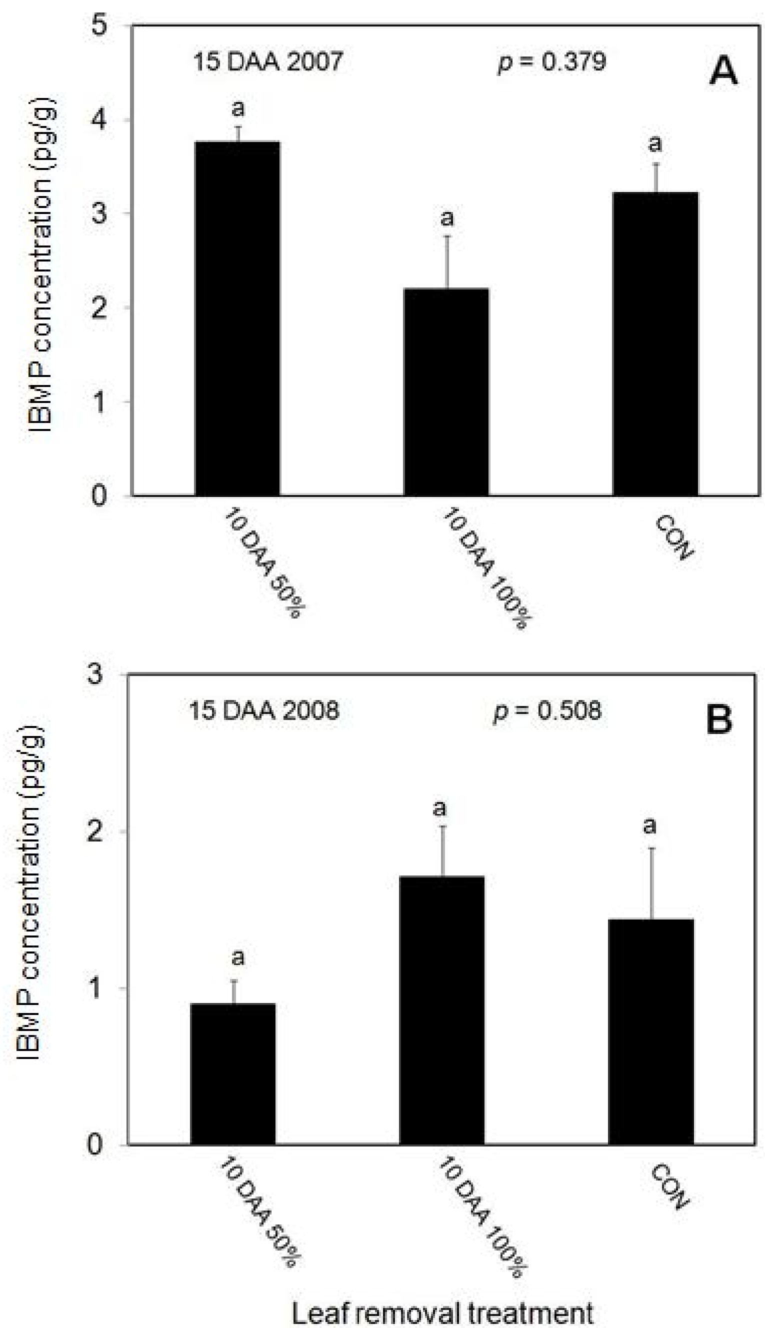


Appendix 2.1 Impact of basal leaf removal timing and severity on IBMP concentration in Finger Lakes Cabernet franc at 15 days after anthesis in **(A)** 2007 and **(B)** 2008. Values are mean ± SE. Means indicated by the same letter are not significantly different at $p \leq 0.05$ Fisher's LSD.

Appendix 3.1 IBMP concentration in Cabernet franc berries in 2008 and 2009.

	IBMP concentration (pg/g)					
	2008			2009		
Vine[a]	30 DAA	50 DAA	Harvest	30 DAA	50 DAA	Harvest
111	69	120	5	8	33	27
112	69	103	4	8	30	12
113	51	117	3	8	31	10
114	51	134	6	9	26	12
115	46	74	6	8	27	8
121	41	67	5	12	33	13
122	39	83	4	8	29	9
123	63	86	4	10	33	22
124	92	138	4	13	36	19
125	94	103	4	6	14	6
211	100	111	5	25	19	5
212	100	115	3	26	30	6
213	133	138	5	21	37	7
214	100	176	6	33	33	5
215	92	185	6	25	34	4
221	110	155	10	17	35	9
222	99	170	8	19	38	7
223	136	207	10	14	36	9
224	98	208	12	25	52	5
225	153	211	11	19	40	7
311	82	102	17	9	23	10
312	54	153	23	10	24	7
313	51	151	21	10	21	8
314	90	81	19	9	16	9
315	101	140	13	5	20	7
321	30	83	3	4	11	8
322	12	85	3	3	15	10
323	14	79	2	3	13	5
324	26	77	8	4	17	11
325	37	81	9	8	14	8
411	73	81	4	9	35	7
412	129	107	9	20	35	8
413	120	121	13	6	32	5
414	103	100	11	11	24	12
415	52	104	7	-	-	-
421	68	92	9	10	36	7
422	83	129	11	10	26	7
423	88	118	14	24	37	9

424	52	129	8	23	36	10
425	98	95	9	18	34	6
511	113	125	17	14	45	7
512	65	64	26	16	47	4
513	88	78	12	15	60	6
514	129	123	15	16	45	10
515	126	84	13	19	60	8
521	108	125	10	21	51	7
522	102	97	13	20	48	8
523	91	104	10	16	63	9
524	90	103	10	14	40	20
525	92	140	7	27	52	9
611	33	84	10	31	62	8
612	41	96	13	25	48	8
613	33	69	15	27	52	16
614	37	81	15	31	59	10
615	48	133	15	30	61	11
621	79	127	9	27	64	10
622	58	135	12	50	66	7
623	42	116	7	46	64	9
624	49	118	7	25	60	19
625	70	115	12	35	65	14
711	113	282	3	-	-	-
712	65	167	2	-	-	-
713	88	246	3	-	-	-
714	129	224	3	-	-	-
715	126	215	3	-	-	-
721	108	192	4	-	-	-
722	102	150	2	-	-	-
723	91	221	3	-	-	-
724	90	124	4	-	-	-
725	92	173	2	-	-	-
731	117	229	16	32	90	4
732	100	226	10	30	78	10
733	102	148	11	37	94	20
734	92	162	11	37	87	7
735	100	113	7	33	86	10
811	73	276	10	43	20	2
812	129	145	11	52	21	10
813	120	239	12	39	15	5
814	103	259	11	34	16	6
815	52	250	11	40	7	6
821	68	319	14	49	16	6
822	83	176	10	35	6	5

823	88	244	11	45	7	1
824	52	229	16	35	4	2
825	98	248	15	44	6	3
911	81	92	3	-	-	-
912	93	95	1	-	-	-
913	45	76	1	-	-	-
914	61	98	1	-	-	-
915	74	128	2	-	-	-
921	79	97	1	-	-	-
922	97	127	1	-	-	-
923	40	121	1	-	-	-
924	92	160	1	-	-	-
925	86	90	1	-	-	-
1011	-[b]	68	4	-	-	-
1012	-	105	3	-	-	-
1013	-	51	5	-	-	-
1014	-	89	4	-	-	-
1015	-	57	7	-	-	-
1021	-	69	7	-	-	-
1022	-	105	6	-	-	-
1023	-	85	8	-	-	-
1024	-	63	9	-	-	-
1025	-	48	7	-	-	-

[a]Number indicates site, panel, vine.
[b]Not measured.

Appendix 3.2 Vine canopy characteristics measured in the fruiting zone with EPQA at anthesis in 2008.

	EPQA metric[b]											
Vine[a]	**PG**	**LLN**	**PIL**	**PIC**	**OLN**	**CEL**	**LEL**	**EP1**	**CEFA**	**CEFA***	**LEFA**	**LEFA***
111	6.70	1.47	9.10	0.00	1.53	0.00	0.09	0.04	0.52	0.52	0.63	0.63
112	7.70	1.69	13.6	66.7	2.15	0.67	0.14	0.09	0.22	0.22	0.53	0.53
113	5.30	2.05	20.5	66.7	2.37	0.83	0.21	0.10	0.22	0.22	0.47	0.47
114	0.00	1.85	16.7	0.00	2.08	0.00	0.17	0.10	0.70	0.70	0.50	0.50
115	0.00	1.47	4.50	50.0	1.60	0.50	0.05	0.13	0.35	0.35	0.69	0.69
121	0.00	2.00	5.90	100.0	2.12	1.00	0.09	0.09	0.53	0.09	0.53	0.53
122	0.00	1.80	14.8	33.3	2.20	0.33	0.12	0.40	0.52	0.08	0.52	0.00
123	8.30	1.75	9.50	80.0	2.17	0.80	0.09	0.18	0.52	0.07	0.52	0.00
124	0.00	1.92	8.70	75.0	2.25	0.75	0.03	0.15	0.51	0.10	0.51	0.00
125	6.70	1.60	8.30	20.0	1.93	0.20	0.06	0.44	0.52	0.19	0.52	0.00
211	7.10	1.83	22.1	55.6	2.48	0.59	0.25	0.10	0.29	0.15	0.45	0.22
212	0.00	1.79	19.7	40.9	2.44	0.41	0.20	0.09	0.36	0.16	0.47	0.24
213	2.90	1.89	22.7	42.1	2.43	0.42	0.24	0.09	0.36	0.11	0.45	0.26
214	3.40	1.52	15.9	25.0	2.07	0.25	0.16	0.07	0.53	0.50	0.48	0.45
215	9.10	1.67	16.4	45.0	2.27	0.45	0.16	0.13	0.38	0.20	0.48	0.22
221	0.00	2.19	25.0	64.7	2.74	0.71	0.25	0.12	0.28	0.15	0.44	0.18
222	2.60	2.29	27.6	71.9	3.13	0.81	0.31	0.19	0.25	0.08	0.42	0.21
223	0.00	2.57	29.2	70.6	3.18	0.71	0.31	0.17	0.26	0.00	0.40	0.21
224	6.90	2.21	31.3	82.4	2.79	1.06	0.34	0.18	0.23	0.03	0.43	0.23
225	3.60	2.00	23.2	50.0	2.50	0.50	0.23	0.06	0.28	0.25	0.44	0.42
311	5.90	2.06	14.3	83.3	2.41	0.83	0.14	0.22	0.26	0.00	0.52	0.00
312	11.8	1.53	3.80	66.7	1.71	0.67	0.04	0.13	0.27	0.17	0.60	0.56
313	0.00	1.56	4.00	40.0	1.88	0.40	0.04	0.16	0.49	0.40	0.61	0.56

314	10.5	1.32	8.00	40.0	1.84	0.50	0.08	0.17	0.42	0.35	0.60	0.54
315	11.8	1.12	0.00	16.7	1.47	0.17	0.00	0.16	0.65	0.58	0.66	0.61
321	7.30	1.34	8.20	13.8	1.70	0.14	0.08	0.16	0.57	0.36	0.61	0.44
322	7.10	1.14	6.30	14.3	1.64	0.14	0.06	0.12	0.56	0.50	0.63	0.59
323	10.5	1.42	7.40	20.0	1.68	0.20	0.07	0.11	0.54	0.50	0.58	0.54
324	14.3	1.21	0.00	0.00	1.43	0.00	0.00	0.10	0.55	0.50	0.66	0.62
325	5.60	1.39	12.0	25.0	1.83	0.25	0.12	0.14	0.46	0.38	0.60	0.56
411	5.00	1.45	24.1	40.0	2.20	0.47	0.28	0.11	0.44	0.40	0.48	0.45
412	9.50	2.10	31.8	78.3	3.19	1.00	0.36	0.20	0.24	0.15	0.40	0.35
413	4.30	1.74	22.5	65.0	2.61	0.70	0.23	0.05	0.22	0.20	0.46	0.45
414	9.10	1.18	11.5	43.8	1.91	0.44	0.12	0.03	0.42	0.41	0.53	0.52
415	26.9	1.27	15.2	30.0	1.65	0.30	0.15	0.02	0.51	0.50	0.45	0.44
421	11.1	1.83	27.3	44.4	2.33	0.44	0.30	0.06	0.37	0.33	0.41	0.39
422	8.70	1.26	13.8	21.4	1.87	0.21	0.14	0.04	0.52	0.50	0.50	0.48
423	9.50	1.38	13.8	41.7	1.95	0.42	0.17	0.04	0.35	0.33	0.53	0.52
424	15.8	2.26	37.2	71.4	3.00	0.79	0.49	0.18	0.26	0.18	0.36	0.31
425	14.3	1.38	17.2	58.3	1.95	0.58	0.21	0.01	0.26	0.25	0.52	0.52
511	10.5	1.63	12.9	80.0	1.89	1.00	0.13	0.09	0.16	0.00	0.56	0.00
512	10.0	1.60	15.6	33.3	2.05	0.44	0.16	0.11	0.38	0.33	0.51	0.47
513	0.00	2.30	23.9	50.0	2.60	0.50	0.26	0.17	0.37	0.25	0.46	0.40
514	5.90	2.12	19.4	77.8	2.65	0.89	0.19	0.18	0.21	0.11	0.47	0.42
515	0.00	2.29	23.1	80.0	2.59	0.80	0.23	0.18	0.21	0.10	0.48	0.42
521	0.00	1.14	6.30	12.5	1.71	0.13	0.06	0.09	0.60	0.00	0.62	0.00
522	0.00	1.33	0.00	41.7	2.13	0.42	0.00	0.14	0.45	0.38	0.57	0.53
523	0.00	1.29	16.7	26.7	2.36	0.27	0.17	0.15	0.44	0.37	0.52	0.47
524	35.7	0.71	10.0	22.2	1.36	0.22	0.10	0.03	0.45	0.44	0.51	0.50
525	0.00	1.86	11.5	40.0	2.21	0.40	0.12	0.14	0.40	0.30	0.53	0.48
611	7.10	1.71	16.7	33.3	2.14	0.33	0.17	0.11	0.40	0.00	0.49	0.00
612	0.00	1.38	22.2	11.1	2.08	0.11	0.22	0.18	0.50	0.44	0.57	0.50

613	8.30	1.92	17.4	60.0	2.33	0.60	0.17	0.06	0.24	0.20	0.45	0.43
614	0.00	2.00	19.2	20.0	2.38	0.20	0.19	0.14	0.46	0.40	0.48	0.42
615	9.10	1.86	14.6	83.3	2.14	0.83	0.15	0.13	0.16	0.08	0.52	0.48
621	5.90	2.59	36.4	50.0	2.94	0.67	0.41	0.20	0.35	0.00	0.39	0.00
622	0.00	1.53	3.80	12.5	2.00	0.13	0.04	0.14	0.57	0.50	0.56	0.50
623	3.80	1.19	12.9	0.00	1.81	0.00	0.13	0.23	0.64	0.56	0.62	0.52
624	9.50	1.67	34.3	9.1	2.19	0.09	0.34	0.24	0.56	0.50	0.48	0.39
625	14.3	1.10	0.00	33.3	1.52	0.33	0.00	0.08	0.43	0.39	0.65	0.63
711	0.00	1.84	22.9	25.0	2.26	0.25	0.23	0.09	0.54	0.50	0.46	0.43
712	0.00	1.86	23.1	40.0	2.57	0.40	0.23	0.10	0.40	0.35	0.44	0.40
713	5.90	2.24	31.6	62.5	2.71	0.63	0.34	0.05	0.21	0.19	0.39	0.38
714	5.60	1.61	17.2	14.3	2.00	0.29	0.17	0.05	0.45	0.43	0.50	0.48
715	10.0	1.75	28.6	30.8	2.40	0.31	0.31	0.06	0.41	0.00	0.39	0.00
721	0.00	2.24	18.4	100.0	2.53	1.00	0.18	0.04	0.03	0.00	0.46	0.45
722	0.00	2.00	16.7	40.0	2.33	0.40	0.17	0.07	0.54	0.50	0.44	0.42
723	0.00	2.69	31.4	75.0	3.31	0.88	0.40	0.10	0.18	0.13	0.37	0.34
724	0.00	2.25	25.9	40.0	2.67	0.40	0.26	0.06	0.43	0.40	0.39	0.37
725	0.00	2.25	27.8	66.7	2.81	0.67	0.28	0.10	0.28	0.00	0.42	0.00
811	7.10	1.86	23.1	50.0	2.43	0.63	0.27	0.05	0.34	0.31	0.42	0.40
812	7.10	1.86	26.9	40.0	2.21	0.40	0.35	0.06	0.33	0.30	0.46	0.44
813	0.00	1.87	21.4	33.3	2.07	0.33	0.29	0.07	0.54	0.50	0.50	0.48
814	0.00	2.33	25.0	33.3	2.58	0.33	0.25	0.06	0.37	0.33	0.41	0.39
815	13.3	1.73	19.2	66.7	1.93	0.67	0.19	0.05	0.20	0.00	0.49	0.00
821	0.00	3.33	42.0	80.0	3.67	1.20	0.50	0.11	0.13	0.10	0.32	0.29
822	0.00	3.25	40.4	100.0	3.56	1.20	0.46	0.11	0.06	0.00	0.34	0.31
823	0.00	3.00	35.3	75.0	3.24	0.75	0.37	0.08	0.17	0.13	0.35	0.32
824	7.70	2.62	29.4	100.0	2.85	1.00	0.32	0.05	0.05	0.00	0.37	0.35
825	0.00	2.67	25.0	100.0	3.08	1.20	0.25	0.06	0.03	0.00	0.39	0.00
911	0.00	3.17	40.4	75.0	3.61	1.13	0.49	0.10	0.16	0.13	0.33	0.30

912	0.00	3.44	41.8	100.0	3.94	1.25	0.53	0.21	0.11	0.00	0.35	0.29
913	0.00	3.38	40.9	100.0	4.08	1.33	0.45	0.14	0.06	0.00	0.33	0.30
914	0.00	2.53	31.6	75.0	3.07	0.75	0.34	0.07	0.17	0.13	0.38	0.37
915	0.00	3.27	40.8	87.5	3.80	1.25	0.49	0.13	0.11	0.00	0.33	0.00
921	0.00	1.47	18.2	22.2	2.07	0.22	0.18	0.15	0.61	0.56	0.50	0.45
922	0.00	3.00	36.4	88.9	3.82	1.00	0.52	0.24	0.22	0.06	0.37	0.32
923	0.00	2.20	18.2	100.0	2.40	1.33	0.18	0.12	0.09	0.00	0.49	0.45
924	5.90	2.53	32.6	75.0	2.76	0.75	0.35	0.17	0.20	0.13	0.41	0.36
925	6.70	2.60	30.8	66.7	2.80	0.67	0.31	0.09	0.20	0.17	0.38	0.35
931	7.10	2.93	41.5	71.4	3.43	0.71	0.54	0.15	0.22	0.14	0.33	0.29
932	7.1	3.14	45.5	71.4	3.64	0.71	0.59	0.11	0.20	0.14	0.30	0.27
933	0.0	2.45	33.3	50.0	3.00	0.50	0.41	0.08	0.28	0.25	0.38	0.35
934	0.0	2.73	36.7	57.1	3.36	0.71	0.40	0.10	0.25	0.21	0.35	0.32
935	0.0	3.92	53.2	50.0	4.25	0.50	0.70	0.26	0.35	0.25	0.31	0.23
1011	13.0	2.48	33.3	75.0	2.65	1.00	0.40	0.17	0.20	0.13	0.40	0.34
1012	9.1	2.32	31.4	33.3	2.45	0.33	0.33	0.14	0.39	0.33	0.42	0.37
1013	0.0	2.40	25.0	60.0	2.90	0.60	0.29	0.37	0.43	0.20	0.52	0.38
1014	0.0	2.24	31.6	46.7	3.12	0.47	0.32	0.17	0.36	0.27	0.39	0.34
1015	12.5	2.13	26.5	33.3	2.31	0.33	0.29	0.18	0.42	0.33	0.45	0.38
1021	0.0	2.19	34.3	0.0	2.31	0.00	0.34	0.19	0.52	0.50	0.49	0.43
1022	43.8	1.19	15.8	0.0	1.25	0.00	0.16	0.04	0.52	0.50	0.46	0.45
1023	11.8	1.59	11.1	100.0	1.65	1.00	0.11	0.15	0.15	0.00	0.60	0.56
1024	33.3	1.28	26.1	16.7	1.61	0.17	0.30	0.18	0.56	0.50	0.46	0.39
1025	5.9	2.00	23.5	50.0	2.24	0.75	0.24	0.21	0.35	0.25	0.51	0.44

[a]Number indicates site, panel, vine.

[b]LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.3 Vine canopy characteristics measured in the fruiting zone with EPQA at anthesis in 2009.

Vine[a]	EPQA metric[b]											
	PG	LLN	PIL	PIC	OLN	CEL	LEL	EP1	CEFA	CEFA*	LEFA	LEFA*
111	0.0	2.29	28.1	50.0	2.57	0.50	0.41	0.13	0.46	0.00	0.42	0.00
112	6.7	1.87	28.6	16.7	2.27	0.33	0.32	0.06	0.44	0.42	0.41	0.39
113	5.3	2.16	29.3	50.0	2.47	0.50	0.32	0.12	0.39	0.33	0.42	0.38
114	11.1	1.94	25.7	50.0	2.50	0.50	0.31	0.17	0.37	0.25	0.42	0.37
115	0.0	2.33	33.3	0.0	2.56	0.00	0.38	0.12	0.78	0.75	0.38	0.33
121	0.0	3.00	34.9	90.0	3.48	1.10	0.38	0.15	0.13	0.00	0.37	0.00
122	8.3	2.25	33.3	83.3	2.75	0.83	0.37	0.19	0.22	0.08	0.42	0.37
123	0.0	3.73	51.2	83.3	4.27	1.33	0.63	0.22	0.14	0.08	0.31	0.24
124	0.0	2.17	23.1	50.0	2.33	0.50	0.23	0.08	0.31	0.25	0.47	0.44
125	7.7	1.46	21.1	0.0	1.62	0.00	0.21	0.04	0.76	0.75	0.54	0.53
211	6.3	2.13	23.5	40.0	2.44	0.40	0.26	0.07	0.34	0.00	0.42	0.00
212	8.3	2.33	35.7	50.0	2.67	0.50	0.43	0.20	0.35	0.25	0.42	0.36
213	0.0	2.23	31.0	58.3	3.15	0.83	0.34	0.28	0.31	0.21	0.46	0.36
214	0.0	2.46	43.8	14.3	3.00	0.14	0.53	0.20	0.56	0.50	0.36	0.30
215	6.7	1.67	20.0	50.0	2.20	0.50	0.24	0.21	0.43	0.00	0.52	0.00
221	0.0	2.14	26.7	75.0	2.71	0.88	0.27	0.14	0.21	0.00	0.45	0.00
222	11.8	1.76	20.0	42.9	2.18	0.43	0.20	0.11	0.35	0.29	0.46	0.42
223	0.0	2.50	37.1	50.0	3.07	0.50	0.54	0.23	0.37	0.25	0.40	0.33
224	6.7	2.53	36.8	66.7	3.13	0.78	0.47	0.13	0.24	0.17	0.35	0.32
225	5.9	2.35	35.0	66.7	3.24	0.80	0.38	0.25	0.29	0.00	0.40	0.00
311	0.0	3.27	42.9	77.8	3.87	1.00	0.53	0.21	0.21	0.11	0.35	0.29
312	0.0	3.18	42.9	77.8	4.00	1.00	0.49	0.27	0.24	0.11	0.37	0.29
313	0.0	3.00	50.0	37.5	3.80	0.38	0.60	0.23	0.40	0.31	0.32	0.25

314	0.0	4.08	55.1	87.5	4.75	2.00	0.76	0.36	0.16	0.06	0.34	0.23
315	0.0	2.55	28.6	83.3	3.09	0.83	0.29	0.25	0.26	0.08	0.45	0.38
321	7.1	1.86	23.1	50.0	2.14	0.50	0.23	0.29	0.35	0.25	0.56	0.46
322	7.7	2.15	28.6	33.3	2.38	0.33	0.36	0.24	0.46	0.33	0.48	0.39
323	0.0	1.75	28.6	14.3	2.33	0.14	0.29	0.30	0.68	0.64	0.50	0.36
324	0.0	2.85	37.8	66.7	3.54	0.78	0.43	0.26	0.30	0.17	0.39	0.31
325	0.0	3.45	44.7	90.9	4.45	1.27	0.61	0.48	0.30	0.05	0.44	0.28
411	4.9	2.34	32.3	57.1	2.85	0.71	0.34	0.08	0.25	0.21	0.38	0.35
412	5.7	2.46	37.2	72.7	2.77	1.00	0.41	0.07	0.16	0.14	0.38	0.36
413	5.1	1.95	25.0	50.0	2.26	0.58	0.26	0.07	0.28	0.25	0.46	0.44
414	10.5	2.03	26.0	80.0	2.29	0.80	0.30	0.18	0.25	0.15	0.47	0.41
421	9.1	1.93	24.7	42.9	2.25	0.57	0.27	0.11	0.40	0.36	0.45	0.41
422	2.6	2.28	30.3	40.0	2.54	0.40	0.33	0.11	0.39	0.35	0.42	0.38
423	8.3	1.86	22.4	27.3	2.17	0.27	0.25	0.06	0.44	0.41	0.44	0.42
424	8.1	1.78	24.2	31.3	2.22	0.31	0.26	0.05	0.43	0.41	0.43	0.42
425	2.6	2.08	25.9	46.7	2.46	0.53	0.27	0.11	0.35	0.30	0.44	0.41
511	9.3	1.63	21.4	35.3	2.02	0.41	0.21	0.20	0.51	0.44	0.51	0.44
512	14.3	1.33	17.9	45.5	1.86	0.45	0.18	0.07	0.44	0.41	0.46	0.45
513	4.8	1.81	17.1	42.1	2.26	0.42	0.17	0.04	0.34	0.32	0.45	0.44
514	6.3	1.97	22.2	54.5	2.31	0.55	0.22	0.18	0.33	0.23	0.49	0.43
515	5.9	2.06	20.0	66.7	2.41	0.67	0.20	0.10	0.23	0.17	0.45	0.41
521	12.8	1.82	22.5	36.4	2.10	0.36	0.23	0.07	0.36	0.32	0.44	0.42
522	5.4	2.24	25.3	63.6	2.54	0.64	0.28	0.10	0.24	0.18	0.42	0.39
523	0.0	2.23	22.4	50.0	2.50	0.50	0.22	0.24	0.39	0.25	0.51	0.42
524	6.5	1.87	22.4	57.7	2.29	0.62	0.24	0.11	0.33	0.27	0.46	0.43
525	4.8	2.00	20.2	66.7	2.43	0.72	0.20	0.06	0.23	0.19	0.45	0.43
611	0.0	3.15	41.5	83.3	3.62	0.83	0.46	0.11	0.14	0.08	0.32	0.29
612	0.0	3.00	40.0	100.0	3.50	1.00	0.50	0.09	0.05	0.00	0.34	0.32
613	0.0	2.73	40.0	25.0	3.09	0.25	0.40	0.10	0.40	0.38	0.34	0.30

614	0.0	3.36	43.2	100.0	3.91	1.00	0.65	0.12	0.07	0.00	0.31	0.28
615	0.0	3.10	51.6	50.0	3.90	0.75	0.58	0.12	0.27	0.25	0.28	0.24
621	0.0	3.05	41.4	66.7	3.21	0.67	0.43	0.29	0.30	0.17	0.41	0.31
622	0.0	2.59	31.8	71.4	3.00	0.71	0.34	0.11	0.22	0.14	0.38	0.35
623	0.0	2.14	22.2	80.0	2.38	0.80	0.22	0.06	0.14	0.10	0.46	0.44
624	0.0	2.83	35.3	75.0	3.17	0.75	0.38	0.22	0.32	0.13	0.39	0.32
625	0.0	3.00	37.3	85.7	3.41	1.00	0.45	0.23	0.21	0.07	0.39	0.31
711	0.0	2.25	33.3	50.0	2.75	0.50	0.33	0.11	0.31	0.25	0.40	0.37
712	0.0	2.75	42.4	50.0	3.42	0.63	0.45	0.12	0.29	0.25	0.33	0.29
713	0.0	2.00	40.9	40.0	2.91	0.50	0.45	0.17	0.45	0.40	0.35	0.30
714	0.0	2.09	30.4	50.0	2.82	0.50	0.35	0.09	0.29	0.25	0.40	0.37
715	0.0	2.27	24.0	83.3	2.82	1.00	0.24	0.08	0.13	0.08	0.42	0.40
811	15.8	1.58	20.0	16.7	1.89	0.17	0.20	0.03	0.43	0.42	0.46	0.45
812	11.1	1.78	15.6	25.0	2.00	0.25	0.16	0.02	0.39	0.38	0.46	0.45
813	21.4	1.64	21.7	33.3	1.86	0.33	0.22	0.02	0.51	0.50	0.42	0.41
814	0.0	2.54	21.2	100.0	2.62	1.00	0.21	0.04	0.02	0.00	0.41	0.39
815	15.0	1.75	28.6	25.0	1.95	0.50	0.29	0.03	0.63	0.63	0.42	0.41
821	11.8	1.71	20.7	50.0	1.82	0.50	0.24	0.04	0.26	0.25	0.51	0.50
822	16.7	1.44	19.2	33.3	1.61	0.33	0.19	0.04	0.68	0.67	0.51	0.50
823	6.3	1.69	22.2	40.0	2.00	0.40	0.26	0.04	0.62	0.60	0.46	0.44
824	12.5	1.75	21.4	0.0	1.88	0.00	0.21	0.02	0.51	0.50	0.47	0.46
825	0.0	1.67	16.0	33.3	1.87	0.33	0.16	0.03	0.52	0.50	0.55	0.54

[a]Number indicates site, panel, vine.

[b] LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.4 Vine canopy characteristics measured in the fruiting zone with EPQA at 30 days after anthesis in 2008.

	EPQA metric[b]											
Vine[a]	PG	LLN	PIL	PIC	OLN	CEL	LEL	EP1	CEFA	CEFA*	LEFA	LEFA*
111	6.67	11.9	0.0	1.85	0.00	0.12	0.41	0.74	0.38	0.65	0.31	11.9
112	7.69	19.4	30.8	2.13	0.31	0.19	0.11	0.43	0.13	0.48	0.22	19.4
113	5.26	14.7	11.1	1.79	0.11	0.15	0.05	0.68	0.00	0.52	0.00	14.7
114	0.00	12.8	50.0	2.13	0.50	0.13	0.05	0.28	0.00	0.51	0.00	12.8
115	0.00	18.2	50.0	2.17	0.50	0.18	0.23	0.56	0.00	0.52	0.00	18.2
121	0.00	12.5	37.5	1.82	0.38	0.13	0.17	0.40	0.23	0.62	0.39	12.5
122	0.00	11.1	25.0	1.86	0.25	0.11	0.21	0.50	0.46	0.61	0.61	11.1
123	8.33	12.5	0.0	1.71	0.00	0.13	0.05	0.68	0.52	0.55	0.31	12.5
124	0.00	22.0	40.0	2.39	0.40	0.22	0.06	0.34	0.00	0.43	0.00	22.0
125	6.67	2.8	0.0	1.47	0.00	0.03	0.08	0.67	0.00	0.64	0.00	2.80
211	7.14	21.6	31.6	2.41	0.32	0.24	0.16	0.52	0.23	0.46	0.28	21.6
212	0.00	26.2	48.4	2.91	0.52	0.29	0.21	0.38	0.18	0.44	0.30	26.2
213	2.86	26.2	50.0	2.74	0.50	0.30	0.12	0.35	0.08	0.43	0.28	26.2
214	3.45	24.6	41.7	2.78	0.42	0.26	0.20	0.42	0.14	0.44	0.31	24.6
215	9.09	31.6	52.2	2.67	0.57	0.37	0.07	0.36	0.22	0.38	0.23	31.6
221	6.67	20.0	37.9	2.41	0.48	0.25	0.04	0.35	0.13	0.44	0.26	20.0
222	0.00	22.0	50.0	2.69	0.50	0.22	0.06	0.31	0.14	0.43	0.24	22.0
223	3.13	19.1	43.3	2.33	0.43	0.19	0.03	0.31	0.14	0.47	0.26	19.1
224	0.00	22.0	36.8	2.40	0.37	0.22	0.04	0.36	0.16	0.44	0.23	22.0
225	3.57	15.8	21.4	2.00	0.21	0.16	0.05	0.55	0.54	0.50	0.49	15.8
311	10.34	25.0	27.3	1.96	0.36	0.28	0.17	0.51	0.27	0.47	0.17	25.0
312	10.34	9.1	12.5	1.65	0.13	0.09	0.08	0.62	0.25	0.55	0.32	9.10
313	9.68	4.3	33.3	1.90	0.33	0.04	0.13	0.49	0.43	0.63	0.59	4.30

314	14.29	9.1	6.3	1.65	0.06	0.09	0.12	0.58	0.53	0.61	0.57	9.10
315	0.00	24.2	30.0	2.21	0.30	0.24	0.14	0.46	0.40	0.47	0.42	24.2
321	10.34	13.9	17.6	2.04	0.18	0.14	0.22	0.55	0.21	0.54	0.21	13.9
322	10.34	4.3	15.4	1.64	0.15	0.04	0.17	0.68	0.62	0.58	0.52	4.30
323	9.68	0.0	7.1	1.45	0.07	0.00	0.17	0.67	0.18	0.74	0.48	0.00
324	14.29	20.0	11.1	1.86	0.11	0.20	0.16	0.55	0.50	0.54	0.48	20.0
325	0.00	11.1	13.3	1.83	0.13	0.11	0.14	0.55	0.30	0.59	0.28	11.1
411	17.65	13.9	15.0	1.49	0.15	0.14	0.22	0.65	0.31	0.60	0.26	13.9
412	17.50	3.7	19.4	1.45	0.19	0.04	0.12	0.61	0.56	0.60	0.57	3.70
413	9.68	13.5	16.7	1.77	0.17	0.14	0.16	0.60	0.53	0.55	0.50	13.5
414	13.89	15.6	27.8	1.75	0.28	0.18	0.16	0.55	0.47	0.55	0.50	15.6
415	18.42	10.0	16.7	1.53	0.17	0.15	0.45	0.73	0.53	0.70	0.54	10.0
421	10.20	14.9	15.2	1.63	0.18	0.15	0.16	0.65	0.39	0.56	0.26	14.9
422	7.69	2.9	10.7	1.62	0.11	0.03	0.11	0.65	0.61	0.59	0.54	2.90
423	0.00	19.1	28.6	2.19	0.33	0.21	0.05	0.47	0.45	0.47	0.46	19.1
424	3.33	17.1	20.0	2.03	0.20	0.20	0.15	0.58	0.25	0.50	0.27	17.1
425	10.81	17.3	44.4	2.14	0.52	0.19	0.26	0.47	0.35	0.53	0.45	17.3
511	17.65	13.5	31.3	1.56	0.31	0.14	0.08	0.53	0.09	0.56	0.47	13.5
512	4.76	20.0	40.0	2.38	0.40	0.20	0.07	0.34	0.30	0.45	0.43	20.0
513	3.85	13.2	41.2	2.12	0.41	0.13	0.08	0.39	0.18	0.52	0.37	13.2
514	0.00	10.0	35.3	2.35	0.35	0.10	0.04	0.37	0.15	0.48	0.42	10.0
515	0.00	17.1	70.0	2.65	0.80	0.17	0.05	0.18	0.15	0.46	0.44	17.1
521	4.17	14.7	27.6	2.02	0.31	0.15	0.15	0.49	0.05	0.54	0.36	14.7
522	7.50	19.3	15.0	1.93	0.15	0.19	0.10	0.61	0.58	0.48	0.45	19.3
523	0.00	13.5	23.5	2.00	0.24	0.16	0.03	0.46	0.21	0.54	0.45	13.5
524	3.45	12.9	14.3	1.79	0.14	0.13	0.14	0.64	0.26	0.55	0.44	12.9
525	2.63	18.5	30.8	2.11	0.31	0.19	0.06	0.48	0.46	0.48	0.46	18.5
611	0.00	19.5	64.3	2.62	0.71	0.22	0.29	0.33	0.18	0.54	0.45	19.5
612	0.00	23.5	83.3	2.86	0.83	0.24	0.23	0.26	0.08	0.47	0.40	23.5

613	0.00	21.4	45.5	2.79	0.45	0.21	0.26	0.43	0.27	0.49	0.39	21.4
614	0.00	13.8	37.5	2.31	0.38	0.14	0.15	0.37	0.31	0.52	0.47	13.8
615	0.00	29.0	37.5	2.79	0.38	0.32	0.25	0.43	0.31	0.46	0.37	29.0
621	9.52	31.0	54.5	2.52	0.64	0.36	0.18	0.32	0.23	0.44	0.39	31.0
622	3.70	18.8	50.0	2.30	0.50	0.19	0.22	0.45	0.11	0.52	0.34	18.8
623	17.39	10.9	7.7	1.48	0.08	0.11	0.15	0.59	0.54	0.62	0.56	10.9
624	11.11	13.6	11.8	1.69	0.12	0.18	0.14	0.56	0.50	0.58	0.53	13.6
625	5.13	18.0	31.6	2.05	0.32	0.20	0.13	0.45	0.11	0.53	0.28	18.0
711	5.56	0.0	0.0	0.94	0.00	0.00	0.04	0.81	0.80	0.81	0.80	0.00
712	0.00	0.0	0.0	0.69	0.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00
713	6.67	0.0	0.0	0.93	0.00	0.00	0.03	0.74	0.73	0.52	0.50	0.00
714	0.00	0.0	0.0	1.00	0.00	0.00	0.03	0.76	0.00	0.81	0.00	0.00
715	0.00	14.3	7.7	1.43	0.08	0.14	0.10	0.68	0.65	0.67	0.64	14.3
721	0.00	0.0	0.0	0.71	0.00	0.00	0.03	0.76	0.75	0.52	0.50	0.00
722	10.00	25.0	5.0	1.33	0.05	0.25	0.24	0.74	0.68	0.50	0.38	25.0
723	0.00	20.0	7.1	1.27	0.07	0.20	0.24	0.74	0.68	0.60	0.50	20.0
724	0.00	0.0	8.3	1.27	0.08	0.00	0.23	0.74	0.67	0.66	0.57	0.00
725	0.00	20.0	0.0	1.33	0.00	0.20	0.22	0.79	0.73	0.67	0.60	20.0
811	13.04	0.0	0.0	1.12	0.00	0.00	0.11	0.81	0.00	0.64	0.00	0.00
812	9.09	0.0	0.0	0.63	0.00	0.00	0.01	0.90	0.90	1.00	1.00	0.00
813	0.00	0.0	0.0	0.56	0.00	0.00	0.01	1.00	1.00	1.00	1.00	0.00
814	0.00	0.0	12.5	0.92	0.13	0.00	0.05	0.64	0.63	0.68	0.67	0.00
815	12.50	0.0	0.0	0.79	0.00	0.00	0.03	1.00	0.00	1.00	0.00	0.00
821	0.00	14.8	33.3	1.89	0.33	0.15	0.07	0.37	0.33	0.57	0.56	14.8
822	43.75	0.0	50.0	2.21	0.50	0.00	0.18	0.42	0.30	0.58	0.52	0.00
823	11.76	0.0	16.7	1.58	0.17	0.00	0.03	0.51	0.50	0.63	0.62	0.00
824	33.33	0.0	50.0	2.08	0.50	0.00	0.15	0.42	0.31	0.60	0.56	0.00
825	5.88	0.0	20.0	1.92	0.20	0.00	0.08	0.49	0.00	0.59	0.00	0.00
911	0.00	13.6	20.0	2.18	0.20	0.14	0.04	0.45	0.43	0.45	0.43	13.6

912	0.00	5.3	18.2	2.00	0.18	0.05	0.09	0.50	0.45	0.56	0.53	5.30
913	5.88	4.8	40.0	2.21	0.40	0.05	0.03	0.32	0.00	0.53	0.00	4.80
914	5.56	13.3	33.3	2.18	0.33	0.13	0.10	0.45	0.39	0.46	0.43	13.3
915	10.00	20.0	20.0	2.14	0.20	0.20	0.12	0.52	0.00	0.45	0.00	20.0
921	0.00	25.0	14.3	1.70	0.14	0.25	0.11	0.60	0.57	0.53	0.50	25.0
922	0.00	15.8	16.7	1.63	0.17	0.16	0.04	0.51	0.50	0.54	0.53	15.8
923	0.00	11.5	14.3	1.65	0.14	0.12	0.14	0.61	0.57	0.59	0.54	11.5
924	0.00	10.0	20.0	1.84	0.20	0.10	0.17	0.46	0.40	0.57	0.50	10.0
925	0.00	5.0	28.6	1.80	0.29	0.05	0.10	0.40	0.36	0.61	0.58	5.00
931	7.14	35.5	54.5	3.23	0.64	0.39	0.13	0.28	0.23	0.37	0.34	35.5
932	7.14	41.9	66.7	3.25	0.89	0.49	0.13	0.22	0.17	0.35	0.31	41.9
933	0.00	46.5	45.5	3.18	0.55	0.51	0.20	0.38	0.32	0.33	0.27	46.5
934	0.00	31.3	61.5	2.81	0.62	0.31	0.16	0.30	0.23	0.39	0.34	31.3
935	13.33	37.1	80.0	3.75	0.90	0.40	0.21	0.20	0.10	0.37	0.31	37.1
1011	0.00	28.0	69.9	2.74	0.09	0.34	0.12	0.42	1.00	0.82	0.00	28.0
1012	0.00	27.7	69.8	2.73	0.09	0.34	0.13	0.42	1.00	0.83	0.00	27.7
1013	0.00	29.0	68.3	2.73	0.09	0.34	0.12	0.43	1.00	0.82	0.00	29.0
1014	7.69	28.0	68.9	2.73	0.09	0.34	0.11	0.42	1.00	0.82	0.00	28.0
1015	0.00	28.2	68.7	2.71	0.09	0.35	0.13	0.42	1.00	0.82	0.00	28.2
1021	0.00	26.9	71.8	2.72	0.09	0.35	0.15	0.43	1.00	0.82	0.00	26.9
1022	0.00	25.1	73.5	2.73	0.09	0.35	0.15	0.42	1.00	0.82	0.00	25.1
1023	0.00	26.9	72.1	2.73	0.18	0.35	0.13	0.42	1.00	0.82	0.00	26.9
1024	0.00	26.5	72.3	2.73	0.09	0.35	0.13	0.42	1.00	0.82	0.00	26.5
1025	0.00	25.7	71.5	2.89	0.09	0.37	0.17	0.35	1.00	0.82	0.00	25.7

[a]Number indicates site, panel, vine.

[b] LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.5 Vine canopy characteristics in the fruiting zone measured with EPQA at 30 days after anthesis in 2009.

	EPQA metric[b]											
Vine[a]	PG	LLN	PIL	PIC	OLN	CEL	LEL	EP1	CEFA	CEFA*	LEFA	LEFA*
111	25.00	0.44	14.29	8.3	1.19	0.08	0.14	0.34	0.75	0.00	0.65	0.00
112	37.50	0.31	0.00	14.3	0.75	0.14	0.00	0.22	0.82	0.79	0.84	0.80
113	29.41	0.41	0.00	12.5	0.88	0.13	0.00	0.54	0.90	0.81	0.85	0.71
114	27.78	0.39	0.00	16.7	1.06	0.17	0.00	0.58	0.83	0.63	0.85	0.71
115	8.33	0.42	0.00	0.0	1.00	0.00	0.00	0.38	0.96	0.93	0.88	0.80
121	41.18	0.29	0.00	0.0	0.76	0.00	0.00	0.09	0.77	0.00	0.82	0.00
122	31.25	0.38	0.00	0.0	0.88	0.00	0.00	0.36	0.84	0.75	0.84	0.75
123	13.33	0.60	0.00	0.0	1.07	0.00	0.00	0.12	0.69	0.64	0.90	0.89
124	25.00	0.58	0.00	0.0	0.83	0.00	0.00	0.03	0.68	0.67	1.00	1.00
125	30.77	0.54	0.00	0.0	0.77	0.00	0.00	0.34	0.89	0.83	0.95	0.93
211	0.00	2.29	35.90	40.0	2.88	0.40	0.44	0.06	0.43	0.00	0.34	0.00
212	12.50	1.88	30.00	50.0	2.13	0.50	0.40	0.15	0.47	0.38	0.44	0.40
213	0.00	2.29	33.33	40.0	2.88	0.60	0.41	0.21	0.43	0.35	0.42	0.35
214	0.00	2.29	35.90	50.0	2.88	0.50	0.41	0.21	0.37	0.25	0.42	0.36
215	0.00	1.76	30.00	25.0	2.47	0.33	0.40	0.19	0.49	0.42	0.45	0.38
221	0.00	2.56	31.71	62.5	3.06	0.63	0.34	0.15	0.25	0.00	0.39	0.00
222	6.67	2.13	25.00	100.0	2.47	1.00	0.25	0.21	0.16	0.00	0.48	0.42
223	13.33	1.80	29.63	80.0	2.13	1.00	0.37	0.14	0.16	0.10	0.48	0.44
224	6.25	1.94	32.26	37.5	2.44	0.38	0.35	0.15	0.51	0.44	0.40	0.35
225	0.00	2.43	35.29	42.9	2.93	0.57	0.35	0.20	0.36	0.29	0.41	0.34
311	0.00	3.20	45.83	62.5	3.73	0.88	0.60	0.40	0.36	0.19	0.41	0.27
312	0.00	3.31	46.51	84.6	4.31	1.08	0.63	0.30	0.21	0.08	0.35	0.27
313	0.00	4.00	56.25	81.8	4.92	1.18	0.81	0.35	0.23	0.09	0.32	0.22

314	0.00	3.31	50.94	58.3	4.06	0.67	0.58	0.25	0.30	0.21	0.33	0.25
315	0.00	2.85	37.84	66.7	3.31	0.67	0.46	0.32	0.37	0.17	0.42	0.31
321	5.56	2.11	31.58	44.4	2.61	0.56	0.42	0.30	0.44	0.33	0.47	0.36
322	0.00	2.36	30.30	71.4	2.86	0.71	0.36	0.22	0.24	0.14	0.45	0.38
323	0.00	2.58	32.26	100.0	2.92	1.00	0.35	0.26	0.21	0.00	0.45	0.37
324	0.00	2.93	43.18	76.9	3.80	1.00	0.50	0.34	0.27	0.12	0.40	0.30
325	0.00	2.15	32.14	54.5	3.00	0.55	0.36	0.29	0.37	0.23	0.44	0.34
411	0.00	2.28	31.51	47.4	2.88	0.58	0.34	0.17	0.34	0.26	0.42	0.36
412	0.00	3.00	43.59	68.8	3.62	0.75	0.55	0.17	0.26	0.19	0.33	0.29
413	5.00	2.65	30.19	100.0	3.30	1.08	0.32	0.17	0.10	0.00	0.40	0.35
414	5.41	2.08	33.77	57.1	2.65	0.67	0.40	0.25	0.42	0.31	0.44	0.36
421	0.00	2.36	35.90	31.3	2.85	0.31	0.44	0.20	0.45	0.38	0.40	0.33
422	0.00	2.70	34.83	64.7	3.21	0.65	0.37	0.14	0.25	0.18	0.38	0.33
423	2.94	2.24	23.68	66.7	2.68	0.73	0.24	0.16	0.26	0.17	0.45	0.39
424	5.56	1.92	21.74	63.6	2.53	0.73	0.22	0.21	0.36	0.25	0.48	0.41
425	0.00	2.32	27.85	61.5	2.71	0.62	0.30	0.13	0.30	0.23	0.43	0.39
511	0.00	1.89	23.61	45.8	2.53	0.50	0.26	0.19	0.39	0.31	0.48	0.42
512	10.53	1.42	11.11	46.7	2.21	0.47	0.11	0.09	0.36	0.30	0.47	0.44
513	8.33	1.58	15.79	40.0	2.14	0.45	0.16	0.06	0.38	0.35	0.47	0.45
514	4.76	2.10	25.00	71.4	2.76	0.71	0.30	0.19	0.29	0.18	0.44	0.39
515	0.00	2.35	32.50	66.7	3.24	0.73	0.35	0.20	0.27	0.17	0.41	0.35
521	0.00	2.03	19.72	50.0	2.43	0.57	0.23	0.13	0.32	0.25	0.48	0.44
522	3.03	2.12	21.43	77.8	2.67	0.83	0.21	0.13	0.19	0.11	0.46	0.42
523	0.00	2.33	28.57	70.0	2.89	0.70	0.29	0.19	0.24	0.15	0.44	0.38
524	5.26	1.84	25.71	46.2	2.53	0.54	0.29	0.16	0.38	0.31	0.44	0.39
525	2.63	2.32	28.41	60.9	2.92	0.65	0.31	0.14	0.30	0.22	0.41	0.36
611	0.00	3.15	41.46	83.3	3.62	0.83	0.46	0.11	0.14	0.00	0.32	0.29
612	0.00	3.00	40.00	100.0	3.50	1.00	0.50	0.09	0.05	0.37	0.34	0.32
613	0.00	2.73	40.00	25.0	3.09	0.25	0.40	0.10	0.40	0.42	0.34	0.30

614	0.00	3.36	43.24	100.0	3.91	1.00	0.65	0.12	0.07	0.39	0.31	0.28
615	0.00	3.10	51.61	50.0	3.90	0.75	0.58	0.12	0.27	0.41	0.28	0.24
621	7.69	2.23	36.21	37.5	2.54	0.38	0.40	0.11	0.49	0.44	0.37	0.34
622	0.00	3.07	36.96	100.0	3.47	1.17	0.41	0.09	0.06	0.00	0.34	0.32
623	0.00	2.13	29.41	44.4	2.50	0.44	0.37	0.06	0.42	0.39	0.40	0.38
624	0.00	2.92	34.29	80.0	3.33	0.80	0.34	0.11	0.17	0.10	0.36	0.33
625	0.00	2.56	36.96	50.0	3.11	0.50	0.43	0.07	0.33	0.30	0.35	0.33
711	0.00	1.76	23.33	33.3	2.47	0.33	0.27	0.22	0.43	0.33	0.50	0.42
712	18.75	0.88	7.14	22.2	1.44	0.22	0.07	0.05	0.57	0.33	0.58	0.57
713	20.00	1.33	20.00	28.6	1.80	0.29	0.20	0.35	0.59	0.60	0.58	0.45
714	0.00	1.45	18.75	25.0	2.18	0.25	0.19	0.20	0.57	0.20	0.51	0.44
715	0.00	1.33	6.25	28.6	1.92	0.29	0.06	0.16	0.45	0.50	0.64	0.59
811	7.14	2.07	44.83	44.4	2.71	0.44	0.52	0.08	0.36	0.33	0.35	0.33
812	0.00	2.57	38.89	50.0	3.29	0.50	0.47	0.10	0.29	0.25	0.34	0.31
813	8.33	2.08	20.00	100.0	2.33	1.00	0.20	0.04	0.04	0.00	0.43	0.42
814	0.00	3.00	36.11	100.0	3.50	1.00	0.42	0.09	0.06	0.00	0.34	0.32
815	11.11	2.00	33.33	71.4	2.78	0.93	0.33	0.08	0.24	0.21	0.37	0.35
821	0.00	2.50	40.00	40.0	2.86	0.40	0.46	0.12	0.53	0.50	0.35	0.31
822	6.25	2.50	40.00	0.0	2.69	0.00	0.48	0.14	0.71	0.67	0.36	0.31
823	7.69	2.08	33.33	100.0	2.23	1.00	0.41	0.06	0.05	0.00	0.44	0.43
824	7.14	2.14	28.33	66.7	2.46	0.78	0.32	0.06	0.20	0.17	0.41	0.39
825	11.11	2.00	33.33	71.4	2.78	0.93	0.33	0.10	0.25	0.21	0.37	0.35

[a]Number indicates site, panel, vine.

[b]LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.6 Vine canopy characteristics in the fruiting zone measured with EPQA at 50DAA in 2008.

	EPQA metric[b]											
Vine[a]	PG	LLN	PIL	PIC	OLN	CEL	LEL	EP1	CEFA	CEFA*	LEFA	LEFA*
111	19.2	1.42	16.2	33.3	1.77	0.33	0.16	0.02	0.57	0.57	0.44	0.44
112	4.0	1.40	14.3	23.1	1.92	0.23	0.14	0.02	0.51	0.36	0.51	0.25
113	13.6	1.77	28.2	37.5	2.14	0.38	0.31	0.03	0.39	0.00	0.42	0.00
114	0.0	2.20	25.0	66.7	2.50	1.00	0.25	0.15	0.22	0.22	0.48	0.46
115	3.6	1.79	22.0	30.0	2.14	0.30	0.22	0.05	0.38	0.00	0.48	0.00
121	20.8	1.42	8.8	66.7	1.67	0.67	0.09	0.02	0.18	0.09	0.54	0.34
122	13.0	1.65	18.4	42.9	1.96	0.43	0.18	0.12	0.36	0.09	0.51	0.30
123	0.0	1.97	17.4	12.5	2.20	0.13	0.19	0.07	0.46	0.00	0.48	0.00
124	10.5	1.79	14.7	71.4	2.16	0.71	0.15	0.07	0.25	0.00	0.48	0.00
125	5.3	1.58	11.7	27.8	2.05	0.28	0.12	0.21	0.55	0.00	0.55	0.00
211	19.4	0.83	16.7	23.1	1.56	0.23	0.20	0.05	0.59	0.19	0.48	0.37
212	15.2	1.09	19.4	34.5	1.97	0.34	0.22	0.05	0.45	0.43	0.44	0.43
213	5.9	1.21	19.5	29.6	2.00	0.30	0.22	0.10	0.52	0.48	0.48	0.45
214	9.1	1.30	16.3	36.0	2.06	0.36	0.16	0.03	0.45	0.16	0.46	0.28
215	20.6	1.18	12.5	25.0	1.65	0.25	0.13	0.07	0.46	0.22	0.52	0.34
221	3.6	2.04	29.8	57.1	2.79	0.62	0.32	0.06	0.29	0.06	0.37	0.25
222	0.0	1.92	30.0	50.0	2.92	0.58	0.32	0.08	0.34	0.16	0.38	0.23
223	0.0	2.37	31.1	56.3	3.21	0.63	0.31	0.08	0.26	0.05	0.36	0.23
224	4.0	1.72	27.9	17.6	2.40	0.24	0.30	0.04	0.45	0.45	0.40	0.39
225	6.3	1.53	16.3	40.0	2.16	0.40	0.18	0.06	0.43	0.45	0.47	0.47
311	3.3	1.73	21.2	21.4	2.20	0.21	0.21	0.16	0.59	0.28	0.47	0.28
312	4.3	1.57	16.7	37.5	2.26	0.38	0.17	0.25	0.44	0.21	0.56	0.27
313	0.0	1.29	14.8	23.1	1.90	0.31	0.15	0.20	0.58	0.23	0.60	0.30

314	8.0	1.52	18.4	28.6	2.08	0.29	0.18	0.27	0.53	0.18	0.56	0.28
315	9.1	1.50	27.3	29.4	2.27	0.35	0.27	0.51	0.68	0.26	0.59	0.20
321	6.7	1.17	8.6	26.1	1.93	0.30	0.09	0.32	0.59	0.26	0.63	0.42
322	15.4	0.96	12.0	14.3	1.50	0.14	0.12	0.27	0.66	0.15	0.65	0.47
323	10.3	1.14	6.1	6.3	1.69	0.06	0.06	0.26	0.67	0.19	0.62	0.33
324	20.8	1.08	15.4	16.7	1.58	0.17	0.15	0.30	0.62	0.29	0.61	0.29
325	6.5	1.03	0.0	14.3	1.48	0.14	0.00	0.14	0.66	0.32	0.69	0.33
411	10.3	1.03	12.5	37.1	1.92	0.40	0.13	0.15	0.45	0.16	0.58	0.31
412	5.3	1.37	13.5	42.9	2.29	0.43	0.13	0.12	0.42	0.20	0.48	0.23
413	7.4	1.48	17.5	41.7	2.37	0.50	0.18	0.05	0.33	0.31	0.45	0.44
414	13.8	1.34	15.4	36.4	2.10	0.36	0.15	0.03	0.38	0.36	0.45	0.44
415	10.3	1.21	10.6	40.0	1.85	0.40	0.13	0.05	0.41	0.38	0.55	0.54
421	8.8	1.44	20.4	43.3	2.32	0.47	0.27	0.04	0.39	0.37	0.42	0.41
422	5.9	1.71	17.2	57.7	2.47	0.62	0.17	0.05	0.28	0.25	0.45	0.44
423	0.0	1.79	18.0	52.2	2.61	0.52	0.18	0.04	0.28	0.13	0.45	0.24
424	9.1	1.30	23.3	34.5	2.18	0.38	0.23	0.03	0.44	0.22	0.42	0.24
425	5.3	1.58	18.3	48.6	2.55	0.51	0.20	0.05	0.32	0.30	0.43	0.42
511	10.0	1.53	15.2	45.0	2.20	0.45	0.15	0.16	0.37	0.28	0.51	0.47
512	0.0	2.13	18.8	72.7	2.87	0.73	0.19	0.15	0.23	0.14	0.46	0.42
513	0.0	1.64	14.6	33.3	2.36	0.33	0.15	0.10	0.38	0.33	0.50	0.46
514	9.1	1.64	13.9	46.2	2.23	0.46	0.14	0.04	0.33	0.31	0.46	0.44
515	0.0	2.00	11.5	57.1	2.54	0.57	0.12	0.03	0.23	0.21	0.45	0.44
521	0.0	1.46	14.0	16.7	2.23	0.17	0.14	0.04	0.49	0.47	0.45	0.44
522	7.1	1.75	28.6	35.0	2.46	0.35	0.33	0.14	0.48	0.43	0.40	0.36
523	4.5	1.32	10.3	41.7	2.41	0.42	0.10	0.10	0.38	0.33	0.48	0.45
524	0.0	1.25	10.0	26.7	2.19	0.27	0.10	0.06	0.46	0.43	0.49	0.48
525	0.0	2.00	31.0	37.0	2.93	0.41	0.31	0.07	0.36	0.33	0.37	0.34
611	7.7	1.38	22.2	38.5	2.38	0.38	0.22	0.20	0.40	0.00	0.50	0.00
612	7.7	1.15	6.7	25.0	1.77	0.25	0.07	0.08	0.42	0.38	0.62	0.60

613	0.0	1.44	7.7	40.0	2.00	0.40	0.08	0.15	0.48	0.40	0.58	0.54
614	15.4	1.00	7.7	22.2	1.69	0.22	0.08	0.12	0.50	0.44	0.58	0.54
615	0.0	1.20	8.3	25.0	2.00	0.25	0.08	0.09	0.48	0.44	0.57	0.54
621	13.0	1.26	20.7	31.3	1.96	0.31	0.24	0.24	0.58	0.00	0.50	0.00
622	7.4	1.04	7.1	16.7	1.70	0.17	0.07	0.24	0.70	0.61	0.59	0.50
623	8.0	1.12	10.7	18.8	1.76	0.19	0.11	0.26	0.62	0.50	0.62	0.54
624	6.9	1.52	11.4	29.4	2.10	0.29	0.11	0.20	0.49	0.38	0.54	0.47
625	0.0	1.48	12.5	33.3	2.26	0.33	0.13	0.20	0.49	0.38	0.54	0.48
711	42.1	0.11	0.0	0.0	0.63	0.00	0.00	0.01	0.90	0.90	1.00	1.00
712	25.0	0.31	0.0	0.0	0.94	0.00	0.00	0.04	0.81	0.80	0.81	0.80
713	30.8	0.23	0.0	0.0	0.69	0.00	0.00	0.00	1.00	1.00	1.00	1.00
714	33.3	0.07	0.0	0.0	0.93	0.00	0.00	0.03	0.74	0.73	0.52	0.50
715	23.5	0.29	0.0	0.0	1.00	0.00	0.00	0.03	0.76	0.00	0.81	0.00
721	16.7	0.22	25.0	5.0	1.33	0.05	0.25	0.24	0.74	0.68	0.50	0.38
722	20.0	0.33	20.0	7.1	1.27	0.07	0.20	0.24	0.74	0.68	0.60	0.50
723	20.0	0.47	0.0	8.3	1.27	0.08	0.00	0.23	0.74	0.67	0.66	0.57
724	6.7	0.33	20.0	0.0	1.33	0.00	0.20	0.22	0.79	0.73	0.67	0.60
725	17.6	0.29	0.0	0.0	1.12	0.00	0.00	0.11	0.81	0.00	0.64	0.00
811	7.1	0.50	14.3	7.7	1.43	0.08	0.14	0.10	0.68	0.65	0.67	0.64
812	50.0	0.14	0.0	0.0	0.71	0.00	0.00	0.03	0.76	0.75	0.52	0.50
813	43.8	0.13	0.0	0.0	0.56	0.00	0.00	0.01	1.00	1.00	1.00	1.00
814	41.7	0.25	0.0	12.5	0.92	0.13	0.00	0.05	0.64	0.63	0.68	0.67
815	21.4	0.29	0.0	0.0	0.79	0.00	0.00	0.03	1.00	0.00	1.00	0.00
821	42.9	0.10	0.0	0.0	0.62	0.00	0.00	0.05	0.96	0.95	0.76	0.75
822	22.2	0.06	0.0	0.0	0.89	0.00	0.00	0.13	0.88	0.87	1.00	1.00
823	35.7	0.14	0.0	0.0	0.64	0.00	0.00	0.06	1.00	1.00	1.00	1.00
824	38.9	0.11	0.0	0.0	0.61	0.00	0.00	0.04	1.00	1.00	1.00	1.00
825	26.7	0.07	0.0	0.0	0.87	0.00	0.00	0.06	0.84	0.00	1.00	0.00
911	21.4	0.14	0.0	0.0	1.07	0.00	0.00	0.17	0.81	0.77	0.59	0.50

912	26.7	0.13	0.0	0.0	0.80	0.00	0.00	0.10	0.91	0.90	1.00	1.00
913	23.1	0.00	0.0	0.0	0.92	0.00	0.00	0.13	0.86	0.83	0.00	0.00
914	35.7	0.00	0.0	0.0	0.86	0.00	0.00	0.10	0.77	0.75	0.00	0.00
915	20.0	0.07	0.0	0.0	0.93	0.00	0.00	0.07	0.86	0.00	1.00	0.00
921	11.1	1.11	20.0	7.7	1.83	0.08	0.20	0.26	0.69	0.62	0.52	0.40
922	0.0	1.28	17.4	18.8	2.17	0.25	0.17	0.23	0.57	0.47	0.54	0.46
923	4.8	1.38	17.2	25.0	2.14	0.31	0.17	0.32	0.57	0.41	0.57	0.47
924	9.5	1.33	17.9	23.1	1.95	0.23	0.18	0.26	0.63	0.54	0.53	0.43
925	5.9	1.18	20.0	31.3	2.12	0.31	0.20	0.15	0.52	0.00	0.47	0.00
931	0.0	3.00	40.0	75.0	3.80	1.00	0.57	0.17	0.20	0.13	0.34	0.30
932	5.6	2.78	42.0	66.7	3.61	0.93	0.56	0.16	0.23	0.17	0.33	0.29
933	12.5	2.31	43.2	53.3	3.25	0.73	0.49	0.18	0.30	0.23	0.34	0.28
934	5.9	2.24	34.2	66.7	3.47	0.76	0.39	0.37	0.36	0.17	0.44	0.33
935	0.0	2.11	23.7	69.6	3.39	0.74	0.29	0.20	0.26	0.00	0.43	0.00
1011	14.5	1.57	37.5	60.0	1.47	0.05	0.09	0.46	0.20	0.17	0.61	0.27
1012	14.5	1.54	37.1	58.7	1.47	0.05	0.09	0.46	0.20	0.17	0.64	0.27
1013	14.5	1.58	37.7	58.0	1.47	0.04	0.09	0.46	0.20	0.17	0.58	0.27
1014	14.5	1.56	37.2	59.1	1.47	0.05	0.09	0.46	0.20	0.17	0.62	0.27
1015	14.5	1.57	37.1	59.0	1.47	0.05	0.09	0.46	0.20	0.17	0.61	0.27
1021	14.5	1.51	37.2	60.0	1.47	0.07	0.07	0.46	0.20	0.17	0.64	0.27
1022	16.3	1.50	36.9	60.5	1.47	0.07	0.06	0.46	0.20	0.17	0.64	0.27
1023	14.5	1.51	37.6	59.1	1.47	0.06	0.07	0.46	0.20	0.17	0.62	0.27
1024	14.5	1.52	37.0	60.0	1.47	0.07	0.07	0.46	0.20	0.17	0.64	0.27
1025	19.8	1.54	37.2	53.7	1.77	0.07	0.07	0.46	0.21	0.09	0.64	0.36

[a]Number indicates site, panel, vine.

[b]LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.7 Vine canopy characteristics in the fruiting zone measured with EPQA at 50 days after anthesis in 2009.

	EPQA metric[b]											
Site[a]	PG	LLN	PIL	PIC	OLN	CEL	LEL	EP1	CEFA	CEFA*	LEFA	LEFA*
111	15.38	0.23	33.33	0.0	1.08	0.00	0.33	0.30	0.89	0.00	0.65	0.00
112	53.85	0.15	0.00	0.0	0.54	0.00	0.00	0.13	0.91	0.90	0.78	0.75
113	23.08	0.23	0.00	0.0	0.85	0.00	0.00	0.53	0.97	0.94	0.92	0.83
114	28.57	0.14	0.00	0.0	0.86	0.00	0.00	0.51	0.93	0.85	0.88	0.75
115	10.00	0.40	0.00	0.0	1.10	0.00	0.00	0.41	0.87	0.79	0.93	0.88
121	21.43	0.14	0.00	0.0	1.00	0.00	0.00	0.15	0.82	0.79	0.79	0.75
122	33.33	0.33	0.00	0.0	1.08	0.00	0.00	0.44	0.81	0.67	0.72	0.50
123	18.18	0.45	0.00	0.0	1.18	0.00	0.00	0.15	0.84	0.81	0.57	0.50
124	27.27	0.73	12.50	0.0	1.18	0.00	0.13	0.09	0.72	0.70	0.60	0.56
125	33.33	0.33	0.00	0.0	0.78	0.00	0.00	0.34	0.92	0.88	0.89	0.83
211	0.00	2.50	34.29	57.1	3.00	0.71	0.37	0.13	0.34	0.00	0.38	0.00
212	7.14	2.21	35.48	57.1	2.71	0.71	0.39	0.21	0.31	0.21	0.43	0.37
213	0.00	2.54	39.39	55.6	3.23	0.67	0.45	0.17	0.41	0.33	0.35	0.30
214	0.00	2.08	40.00	36.4	3.00	0.36	0.44	0.10	0.44	0.41	0.33	0.30
215	6.25	1.19	15.79	10.0	1.81	0.10	0.16	0.05	0.56	0.55	0.52	0.50
221	0.00	2.71	34.21	70.0	3.43	0.80	0.34	0.16	0.22	0.00	0.38	0.00
222	0.00	2.07	27.59	60.0	2.79	0.80	0.28	0.24	0.33	0.20	0.48	0.41
223	9.09	2.55	32.14	85.7	3.18	1.14	0.32	0.19	0.15	0.07	0.40	0.34
224	9.09	2.45	33.33	83.3	3.00	1.00	0.33	0.20	0.18	0.08	0.41	0.35
225	0.00	2.62	41.18	58.3	3.54	0.75	0.44	0.31	0.35	0.21	0.40	0.31
311	0.00	2.23	37.93	22.2	2.92	0.33	0.38	0.16	0.43	0.39	0.39	0.33
312	0.00	2.27	28.00	50.0	2.82	0.50	0.28	0.31	0.42	0.25	0.49	0.38
313	0.00	2.50	36.67	55.6	3.25	0.56	0.43	0.49	0.49	0.22	0.52	0.33

314	0.00	2.23	34.48	40.0	3.00	0.50	0.34	0.33	0.43	0.30	0.47	0.34
315	0.00	2.08	24.00	57.1	2.67	0.57	0.24	0.29	0.45	0.29	0.50	0.40
321	5.56	1.61	24.14	12.5	2.06	0.13	0.24	0.11	0.53	0.50	0.49	0.45
322	7.14	1.79	16.00	66.7	2.21	0.67	0.16	0.33	0.46	0.25	0.57	0.46
323	13.33	1.33	5.00	20.0	1.67	0.20	0.05	0.15	0.49	0.40	0.60	0.55
324	0.00	2.00	35.71	25.0	2.86	0.25	0.39	0.45	0.57	0.38	0.54	0.34
325	0.00	2.29	28.13	72.7	3.07	0.73	0.31	0.41	0.41	0.14	0.52	0.39
411	0.00	2.28	31.51	47.4	2.88	0.58	0.34	0.08	0.30	0.26	0.39	0.36
412	0.00	3.00	43.59	68.8	3.62	0.75	0.55	0.21	0.28	0.19	0.35	0.29
413	5.00	2.65	30.19	100.0	3.30	1.08	0.32	0.14	0.08	0.00	0.39	0.35
414	5.41	2.08	33.77	57.1	2.65	0.67	0.40	0.19	0.39	0.31	0.42	0.36
421	6.90	1.69	20.41	40.0	2.21	0.40	0.20	0.16	0.44	0.37	0.49	0.44
422	3.45	1.72	14.00	61.9	2.45	0.62	0.16	0.20	0.31	0.19	0.53	0.48
423	6.25	1.72	21.82	42.9	2.38	0.43	0.22	0.13	0.41	0.36	0.45	0.41
424	6.90	1.52	25.00	38.5	2.41	0.38	0.25	0.10	0.42	0.38	0.42	0.39
425	7.69	1.51	16.95	33.3	2.21	0.37	0.17	0.07	0.42	0.39	0.46	0.43
511	0.00	1.89	23.61	45.8	2.53	0.50	0.26	0.22	0.41	0.31	0.49	0.42
512	10.53	1.42	11.11	46.7	2.21	0.47	0.11	0.17	0.41	0.30	0.49	0.44
513	8.33	1.58	15.79	40.0	2.14	0.45	0.16	0.19	0.45	0.35	0.51	0.45
514	4.76	2.10	25.00	71.4	2.76	0.71	0.30	0.26	0.33	0.18	0.46	0.39
515	0.00	2.35	32.50	66.7	3.24	0.73	0.35	0.88	0.84	0.17	0.86	0.35
521	0.00	2.03	19.72	50.0	2.43	0.57	0.23	0.24	0.38	0.25	0.53	0.44
522	3.03	2.12	21.43	77.8	2.67	0.83	0.21	0.25	0.27	0.11	0.50	0.42
523	0.00	2.33	28.57	70.0	2.89	0.70	0.29	0.29	0.30	0.15	0.49	0.38
524	5.26	1.84	25.71	46.2	2.53	0.54	0.29	0.20	0.40	0.31	0.45	0.39
525	2.63	2.32	28.41	60.9	2.92	0.65	0.31	0.23	0.35	0.22	0.44	0.36
611	0.00	1.45	6.25	42.9	2.09	0.43	0.06	0.32	0.55	0.62	0.63	0.53
612	0.00	1.39	9.38	33.3	2.04	0.33	0.09	0.26	0.51	0.33	0.62	0.53
613	0.00	1.29	9.09	38.5	2.06	0.38	0.09	0.17	0.51	0.63	0.55	0.50

614	0.00	1.25	10.00	35.7	2.13	0.36	0.10	0.10	0.44	0.69	0.55	0.53
615	5.26	1.37	30.77	31.3	2.21	0.31	0.35	0.45	0.59	0.79	0.60	0.42
621	17.65	1.12	10.53	15.4	1.50	0.23	0.13	0.23	0.67	0.36	0.62	0.53
622	26.32	1.11	14.29	44.4	1.58	0.44	0.19	0.09	0.38	0.37	0.55	0.52
623	19.05	0.76	12.50	16.7	1.33	0.17	0.13	0.20	0.70	0.42	0.59	0.53
624	10.34	1.10	12.50	7.7	1.55	0.08	0.13	0.08	0.70	0.39	0.56	0.53
625	9.38	1.00	9.38	7.1	1.44	0.07	0.09	0.16	0.82	0.41	0.61	0.55
711	7.14	1.50	38.10	22.2	2.14	0.22	0.38	0.18	0.59	0.56	0.44	0.38
712	0.00	1.07	6.67	33.3	2.14	0.33	0.07	0.13	0.47	0.40	0.56	0.53
713	28.57	0.86	8.33	45.5	1.64	0.45	0.08	0.31	0.47	0.32	0.63	0.54
714	0.00	1.27	21.43	33.3	2.36	0.42	0.21	0.23	0.51	0.42	0.50	0.43
715	0.00	1.29	16.67	30.0	2.00	0.40	0.17	0.17	0.60	0.55	0.52	0.47
811	5.17	2.22	34.88	75.9	3.16	0.94	0.41	0.37	0.36	0.14	0.45	0.22
812	0.00	2.40	33.33	91.7	3.60	1.25	0.42	0.32	0.26	0.08	0.42	0.35
813	5.56	2.31	34.94	73.3	3.14	0.87	0.40	0.39	0.38	0.17	0.46	0.24
814	0.00	2.88	30.43	100.0	4.13	1.20	0.30	0.22	0.13	0.00	0.39	0.35
815	13.33	1.80	33.33	58.3	2.60	0.67	0.44	0.72	0.69	0.25	0.68	0.35
821	7.69	2.69	40.00	87.5	3.31	1.25	0.46	0.31	0.23	0.06	0.41	0.31
822	12.50	2.25	38.89	50.0	2.50	0.50	0.44	0.36	0.43	0.25	0.48	0.35
823	9.09	2.64	37.93	50.0	3.00	1.00	0.41	0.26	0.35	0.25	0.40	0.31
824	8.33	1.92	30.43	20.0	2.33	0.20	0.30	0.16	0.57	0.50	0.42	0.37
825	0.00	2.00	23.08	0.0	2.31	0.00	0.23	0.30	0.60	0.50	0.55	0.42

[a]Number indicates site, panel, vine.

[b]LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.8 Vine canopy characteristics in the fruiting zone measured with EPQA at harvest in 2008.

	EPQA metric[b]											
Vine[a]	**PG**	**LLN**	**PIL**	**PIC**	**OLN**	**CEL**	**LEL**	**EP1**	**CEFA**	**CEFA***	**LEFA**	**LEFA***
111	23.1	0.54	0.00	0.00	0.85	0.00	0.00	0.37	0.92	0.00	0.95	0.00
112	30.0	0.20	0.00	0.00	0.80	0.00	0.00	0.28	1.00	1.00	0.64	0.50
113	30.8	0.23	0.00	0.00	0.77	0.00	0.00	0.48	0.96	0.93	0.91	0.83
114	33.3	0.42	0.00	16.7	0.92	0.17	0.00	0.34	0.76	0.67	0.85	0.80
115	41.7	0.42	0.00	0.00	0.58	0.00	0.00	0.31	1.00	1.00	1.00	1.00
121	21.4	0.50	0.00	0.00	0.86	0.00	0.00	0.00	1.00	0.00	0.86	0.00
122	60.0	0.30	0.00	0.00	0.50	0.00	0.00	0.53	0.88	0.75	0.92	0.83
123	27.3	0.45	0.00	0.00	0.91	0.00	0.00	0.65	0.93	0.80	0.93	0.80
124	9.10	0.55	0.00	0.00	1.00	0.00	0.00	0.65	1.00	1.00	0.94	0.83
125	41.7	0.50	0.00	0.00	0.67	0.00	0.00	0.64	1.00	1.00	0.94	0.83
211	0.00	2.27	26.5	60.0	2.93	0.70	0.26	0.15	0.33	0.33	0.41	0.41
212	0.00	2.36	30.8	42.9	3.00	0.43	0.31	0.14	0.37	0.37	0.39	0.39
213	2.90	2.00	21.4	57.1	2.80	0.61	0.21	0.12	0.28	0.15	0.43	0.29
214	0.00	1.91	19.0	44.4	2.73	0.44	0.19	0.13	0.35	0.35	0.44	0.44
215	8.30	1.92	21.7	55.6	2.67	0.56	0.22	0.18	0.32	0.32	0.45	0.45
221	0.00	2.29	35.9	27.3	2.94	0.27	0.36	0.14	0.47	0.47	0.37	0.37
222	0.00	2.00	15.4	75.0	2.92	0.75	0.15	0.17	0.21	0.21	0.49	0.49
223	0.00	2.00	25.0	60.0	3.07	0.73	0.29	0.16	0.29	0.29	0.43	0.43
224	0.00	2.07	19.4	58.3	2.87	0.67	0.19	0.18	0.31	0.31	0.46	0.46
225	0.00	2.00	33.3	42.9	2.93	0.43	0.37	0.09	0.36	0.36	0.37	0.37
311	6.70	0.93	7.10	33.3	1.93	0.33	0.07	0.32	0.58	0.43	0.62	0.54
312	7.70	0.92	8.30	25.0	1.54	0.25	0.08	0.16	0.51	0.00	0.73	0.00
313	16.7	0.75	0.00	12.5	1.42	0.13	0.00	0.19	0.64	0.00	0.67	0.00

314	0.00	1.18	7.70	12.5	1.91	0.13	0.08	0.25	0.61	0.00	0.63	0.00
315	9.10	0.73	0.00	11.1	1.55	0.11	0.00	0.21	0.65	0.00	0.68	0.00
321	14.3	0.50	0.00	0.00	1.21	0.00	0.00	0.20	0.84	0.80	0.66	0.57
322	16.7	0.92	9.10	0.00	1.25	0.00	0.09	0.31	0.83	0.00	0.73	0.00
323	15.4	0.85	0.00	14.3	1.38	0.14	0.00	0.37	0.71	0.00	0.76	0.00
324	13.3	0.73	0.00	0.00	1.20	0.00	0.00	0.29	0.80	0.00	0.81	0.00
325	0.00	1.23	12.5	27.3	2.08	0.27	0.13	0.41	0.66	0.00	0.64	0.00
411	29.7	0.19	0.00	0.00	0.84	0.00	0.00	0.29	0.90	0.85	0.85	0.79
412	27.8	0.14	0.00	0.00	0.83	0.00	0.00	0.17	0.92	0.46	0.75	0.30
413	10.0	0.65	7.70	0.00	1.30	0.00	0.08	0.24	0.81	0.77	0.71	0.62
414	27.3	0.52	5.90	5.30	1.09	0.05	0.06	0.24	0.77	0.71	0.70	0.62
415	22.9	0.46	0.00	4.50	1.09	0.05	0.00	0.31	0.81	0.41	0.78	0.38
421	22.2	0.44	0.00	5.60	1.11	0.06	0.00	0.25	0.77	0.69	0.76	0.71
422	14.3	0.34	0.00	0.00	1.14	0.00	0.00	0.27	0.86	0.50	0.73	0.17
423	10.9	0.59	7.90	5.60	1.44	0.06	0.08	0.26	0.75	0.20	0.64	0.16
424	6.50	0.55	5.90	3.80	1.39	0.04	0.06	0.27	0.78	0.35	0.71	0.41
425	3.10	0.78	8.00	4.20	1.53	0.04	0.08	0.37	0.78	0.35	0.73	0.34
511	8.30	0.92	4.50	0.00	1.54	0.00	0.05	0.23	0.77	0.70	0.63	0.52
512	0.00	1.13	5.60	25.0	2.13	0.25	0.06	0.34	0.61	0.44	0.62	0.50
513	0.00	0.78	0.00	10.0	1.65	0.10	0.00	0.17	0.69	0.63	0.64	0.58
514	4.80	1.33	7.10	15.4	1.95	0.15	0.07	0.28	0.65	0.54	0.59	0.46
515	0.00	1.00	6.70	23.1	1.87	0.23	0.07	0.38	0.69	0.54	0.67	0.53
521	5.10	0.82	9.40	3.70	1.51	0.04	0.09	0.20	0.78	0.72	0.62	0.55
522	5.30	0.97	16.2	3.70	1.68	0.04	0.16	0.26	0.73	0.65	0.60	0.50
523	7.70	0.54	7.10	0.00	1.42	0.00	0.07	0.13	0.73	0.70	0.63	0.57
524	8.30	0.42	0.00	4.80	1.29	0.05	0.00	0.42	0.85	0.74	0.77	0.65
525	5.90	0.62	9.50	6.70	1.50	0.07	0.10	0.14	0.72	0.68	0.60	0.55
611	0.00	1.08	14.3	23.5	2.38	0.24	0.14	0.34	0.56	0.38	0.59	0.46
612	0.00	1.00	0.00	14.3	2.00	0.14	0.00	0.29	0.60	0.46	0.65	0.54

613	0.00	1.25	20.0	22.2	2.38	0.22	0.20	0.40	0.62	0.44	0.58	0.40
614	0.00	1.10	9.10	25.0	2.30	0.25	0.09	0.25	0.55	0.42	0.53	0.45
615	7.70	1.46	26.3	30.0	2.23	0.30	0.26	0.17	0.55	0.50	0.43	0.37
621	13.6	0.82	27.8	16.0	1.95	0.16	0.28	0.19	0.57	0.50	0.43	0.36
622	4.50	0.77	17.6	0.00	1.64	0.00	0.18	0.07	0.75	0.74	0.45	0.41
623	16.1	0.68	14.3	10.7	1.58	0.11	0.14	0.09	0.64	0.61	0.46	0.43
624	3.10	0.94	10.0	15.6	1.94	0.16	0.10	0.10	0.57	0.53	0.50	0.47
625	0.00	1.76	27.3	31.6	2.52	0.37	0.27	0.22	0.51	0.45	0.46	0.38
711	42.1	0.16	0.00	0.00	0.63	0.00	0.00	0.02	0.89	0.00	1.00	0.00
712	23.5	0.24	0.00	0.00	1.00	0.00	0.00	0.06	0.75	0.73	0.88	0.88
713	23.5	0.29	0.00	0.00	0.82	0.00	0.00	0.07	0.90	0.89	1.00	1.00
714	29.4	0.18	0.00	0.00	1.06	0.00	0.00	0.11	0.73	0.70	0.55	0.50
715	25.0	0.25	0.00	7.10	1.13	0.07	0.00	0.07	0.66	0.64	0.77	0.75
721	15.3	0.36	9.70	4.90	1.32	0.05	0.10	0.23	0.75	0.41	0.63	0.34
722	17.6	0.35	16.7	5.90	1.35	0.06	0.17	0.29	0.73	0.65	0.63	0.50
723	18.8	0.50	0.00	7.70	1.31	0.08	0.00	0.22	0.72	0.65	0.65	0.56
724	5.9	0.47	12.5	5.90	1.47	0.06	0.13	0.16	0.72	0.68	0.62	0.56
725	17.6	0.29	0.00	0.00	1.12	0.00	0.00	0.12	0.81	0.79	0.65	0.60
811	5.9	0.53	11.1	6.70	1.41	0.07	0.11	0.19	0.71	0.00	0.72	0.00
812	35.3	0.29	0.00	0.00	0.94	0.00	0.00	0.07	0.79	0.77	0.53	0.50
813	43.8	0.13	0.00	0.00	0.56	0.00	0.00	0.02	1.00	1.00	1.00	1.00
814	37.5	0.25	0.00	8.30	1.00	0.08	0.00	0.07	0.65	0.63	0.64	0.63
815	18.8	0.38	0.00	0.00	0.88	0.00	0.00	0.07	1.00	1.00	0.85	0.83
821	41.2	0.12	0.00	0.00	0.65	0.00	0.00	0.07	0.95	0.00	0.77	0.00
822	29.4	0.06	0.00	0.00	0.82	0.00	0.00	0.10	0.86	0.85	1.00	1.00
823	31.3	0.13	0.00	0.00	0.75	0.00	0.00	0.06	0.91	0.90	1.00	1.00
824	47.1	0.12	0.00	0.00	0.53	0.00	0.00	0.01	1.00	1.00	1.00	1.00
825	20.0	0.27	0.00	0.00	1.00	0.00	0.00	0.10	0.84	0.82	0.77	0.75
911	18.8	0.31	0.00	0.00	1.19	0.00	0.00	0.22	0.81	0.00	0.61	0.00

912	25.0	0.19	0.00	0.00	0.81	0.00	0.00	0.09	0.91	0.90	1.00	1.00
913	18.8	0.06	0.00	0.00	0.94	0.00	0.00	0.19	0.88	0.86	1.00	1.00
914	37.5	0.06	0.00	0.00	0.81	0.00	0.00	0.17	0.79	0.75	1.00	1.00
915	18.8	0.06	0.00	0.00	0.94	0.00	0.00	0.09	0.87	0.86	1.00	1.00
921	15.4	0.92	0.00	12.5	1.54	0.13	0.00	0.21	0.60	0.50	0.66	0.58
922	5.60	1.33	25.0	16.7	2.00	0.17	0.29	0.18	0.57	0.50	0.52	0.46
923	0.00	1.63	30.8	18.2	2.31	0.18	0.35	0.41	0.66	0.55	0.56	0.38
924	0.00	1.25	8.00	16.7	1.85	0.17	0.08	0.29	0.64	0.54	0.65	0.54
925	0.00	1.21	5.90	42.9	2.21	0.43	0.06	0.24	0.47	0.00	0.60	0.00
931	0.00	3.10	45.2	71.4	3.80	0.86	0.55	0.34	0.31	0.14	0.39	0.29
932	0.00	2.71	34.2	85.7	3.21	1.00	0.39	0.22	0.19	0.07	0.42	0.36
933	0.00	2.29	31.3	54.5	3.07	0.64	0.34	0.42	0.48	0.27	0.50	0.34
934	0.00	2.00	28.6	57.1	3.00	0.71	0.32	0.36	0.42	0.25	0.50	0.38
935	0.00	2.82	41.9	69.2	4.00	0.85	0.48	0.44	0.37	0.00	0.45	0.00
1011	31.5	3.10	1.00	24.1	0.52	0.73	0.73	0.38	0.80	0.64	0.73	0.09
1012	32.7	3.10	0.90	24.2	0.52	0.73	0.73	0.41	0.77	0.64	0.73	0.09
1013	32.7	3.10	0.90	24.1	0.51	0.73	0.73	0.37	0.81	0.64	0.73	0.09
1014	32.7	3.10	1.00	24.6	0.54	0.73	0.73	0.40	0.79	0.64	0.73	0.09
1015	32.7	3.10	1.00	24.1	0.51	0.73	0.73	0.37	0.80	0.64	0.73	0.09
1021	34.8	3.10	1.00	25.0	0.51	0.73	0.73	0.37	0.76	0.64	0.73	0.09
1022	32.7	3.10	0.90	24.6	0.51	0.73	0.73	0.48	0.71	0.64	0.73	0.09
1023	34.1	3.10	1.00	25.0	0.52	0.73	0.73	0.37	0.73	0.64	0.73	0.09
1024	32.7	3.10	1.00	24.4	0.52	0.73	0.73	0.45	0.75	0.64	0.73	0.09
1025	32.7	3.10	0.90	23.5	0.51	0.82	0.82	0.37	0.69	0.73	0.78	0.00

[a]Number indicates site, panel, vine.

[b]LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.9 Vine canopy characteristics in the fruiting zone measured with EPQA at harvest in 2009.

	EPQA metric[b]											
Vine[a]	PG	LLN	PIL	PIC	OLN	CEL	LEL	EP1	CEFA	CEFA*	LEFA	LEFA*
111	33.33	0.13	0.00	8.33	0.93	0.08	0.00	0.50	0.81	0.67	1.00	1.00
112	40.00	0.33	0.00	0.00	0.73	0.00	0.00	0.33	0.83	0.75	0.93	0.90
113	43.75	0.13	0.00	0.00	0.75	0.00	0.00	0.61	0.88	0.70	1.00	1.00
114	47.06	0.24	0.00	0.00	0.65	0.00	0.00	0.60	0.94	0.86	0.90	0.75
115	30.00	0.40	0.00	0.00	0.80	0.00	0.00	0.34	1.00	1.00	0.84	0.75
121	18.18	0.09	0.00	0.00	1.09	0.00	0.00	0.76	0.95	0.77	0.88	0.50
122	53.85	0.23	0.00	0.00	0.62	0.00	0.00	0.59	0.88	0.70	0.93	0.83
123	18.18	0.55	0.00	0.00	1.18	0.00	0.00	0.67	0.93	0.79	0.86	0.58
124	10.00	0.70	0.00	0.00	1.30	0.00	0.00	0.47	0.82	0.67	0.85	0.71
125	40.00	0.60	16.67	0.00	0.90	0.00	0.17	0.45	0.87	0.83	0.75	0.58
211	6.25	1.75	25.00	33.33	2.31	0.33	0.25	0.57	0.73	0.00	0.66	0.00
212	15.38	1.85	29.17	50.00	2.46	0.50	0.29	0.78	0.80	0.31	0.78	0.35
213	0.00	2.00	28.57	36.36	2.79	0.45	0.29	0.58	0.66	0.32	0.64	0.38
214	7.14	1.50	28.57	33.33	2.36	0.42	0.33	0.53	0.66	0.42	0.59	0.38
215	0.00	2.38	29.03	75.00	3.00	0.88	0.35	0.65	0.60	0.19	0.66	0.37
221	0.00	1.58	21.05	41.67	2.58	0.42	0.26	0.50	0.60	0.00	0.62	0.00
222	0.00	1.71	12.50	37.50	2.29	0.38	0.13	0.82	0.86	0.31	0.87	0.48
223	7.14	1.43	15.00	30.77	2.36	0.31	0.15	0.69	0.77	0.35	0.76	0.43
224	0.00	1.46	21.05	30.00	2.23	0.30	0.26	0.95	0.97	0.45	0.95	0.45
225	0.00	1.67	15.00	40.00	2.50	0.40	0.15	0.88	0.90	0.30	0.90	0.45
311	0.00	1.00	16.67	7.69	2.08	0.08	0.17	0.08	0.53	0.50	0.49	0.46
312	6.25	0.94	13.33	28.57	1.81	0.29	0.13	0.16	0.53	0.46	0.60	0.57
313	7.69	0.77	10.00	16.67	1.69	0.17	0.10	0.25	0.63	0.54	0.64	0.55

314	0.00	0.79	0.00	0.00	1.57	0.00	0.00	0.12	0.64	0.59	0.72	0.68
315	0.00	1.31	11.76	33.33	2.23	0.33	0.12	0.23	0.55	0.46	0.52	0.44
321	14.29	0.64	0.00	0.00	1.29	0.00	0.00	0.03	0.68	0.67	0.68	0.67
322	7.69	0.46	0.00	11.11	1.15	0.11	0.00	0.12	0.85	0.83	0.76	0.75
323	13.33	0.73	0.00	0.00	1.27	0.00	0.00	0.08	0.66	0.63	0.75	0.73
324	0.00	0.83	10.00	16.67	1.83	0.17	0.10	0.29	0.61	0.50	0.69	0.60
325	13.33	1.00	20.00	26.67	2.00	0.27	0.20	0.25	0.55	0.43	0.51	0.43
411	0.00	1.66	13.21	46.88	2.66	0.53	0.13	0.34	0.46	0.27	0.56	0.44
412	0.00	1.96	15.56	61.11	2.74	0.67	0.18	0.27	0.37	0.19	0.52	0.43
413	0.00	1.59	16.28	28.57	2.37	0.33	0.16	0.28	0.51	0.38	0.55	0.44
414	6.45	1.23	5.26	40.91	1.94	0.41	0.05	0.23	0.51	0.39	0.61	0.54
421	0.00	1.38	12.12	26.67	2.00	0.33	0.12	0.32	0.62	0.47	0.62	0.52
422	0.00	1.81	17.02	37.50	2.42	0.38	0.17	0.33	0.57	0.41	0.54	0.41
423	7.69	1.38	13.89	14.29	1.92	0.14	0.14	0.20	0.65	0.57	0.52	0.44
424	7.69	0.92	8.33	20.00	1.69	0.20	0.08	0.29	0.68	0.58	0.62	0.52
425	3.85	1.73	22.22	36.84	2.46	0.37	0.22	0.36	0.53	0.37	0.55	0.40
511	13.51	1.05	23.08	17.24	1.84	0.17	0.23	0.22	0.59	0.52	0.52	0.44
512	11.76	1.00	11.76	30.77	1.76	0.31	0.12	0.15	0.56	0.50	0.54	0.50
513	10.53	1.42	14.81	42.86	2.16	0.50	0.15	0.17	0.43	0.36	0.50	0.44
514	0.00	1.75	20.00	46.67	2.50	0.47	0.20	0.28	0.48	0.33	0.52	0.43
515	0.00	1.45	6.25	22.22	2.27	0.22	0.06	0.25	0.53	0.39	0.57	0.47
521	9.38	1.34	6.98	42.11	1.94	0.42	0.07	0.24	0.48	0.34	0.60	0.52
522	6.67	1.73	19.23	45.00	2.40	0.45	0.19	0.40	0.51	0.28	0.59	0.43
523	4.76	1.76	18.92	46.67	2.48	0.47	0.19	0.33	0.45	0.27	0.55	0.43
524	6.25	1.06	11.76	18.75	2.06	0.19	0.12	0.32	0.61	0.47	0.58	0.44
525	0.00	2.00	22.92	47.62	2.88	0.48	0.25	0.48	0.54	0.26	0.58	0.39
611	0.00	1.45	6.25	42.86	2.09	0.43	0.06	0.32	0.55	0.62	0.63	0.53
612	0.00	1.39	9.38	33.33	2.04	0.33	0.09	0.26	0.51	0.33	0.62	0.53
613	0.00	1.29	9.09	38.46	2.06	0.38	0.09	0.17	0.51	0.63	0.55	0.50

614	0.00	1.25	10.00	35.71	2.13	0.36	0.10	0.10	0.44	0.69	0.55	0.53
615	5.26	1.37	30.77	31.25	2.21	0.31	0.35	0.45	0.59	0.79	0.60	0.42
621	17.65	1.12	10.53	15.38	1.50	0.23	0.13	0.23	0.67	0.36	0.62	0.53
622	26.32	1.11	14.29	44.44	1.58	0.44	0.19	0.09	0.38	0.37	0.55	0.52
623	19.05	0.76	12.50	16.67	1.33	0.17	0.13	0.20	0.70	0.42	0.59	0.53
624	10.34	1.10	12.50	7.69	1.55	0.08	0.13	0.08	0.70	0.39	0.56	0.53
625	9.38	1.00	9.38	7.14	1.44	0.07	0.09	0.16	0.82	0.41	0.61	0.55
711	37.50	0.25	0.00	0.00	1.00	0.00	0.00	0.11	0.63	0.58	0.78	0.75
712	28.57	0.07	0.00	0.00	0.93	0.00	0.00	0.07	0.81	0.79	0.54	0.50
713	41.67	0.08	0.00	9.09	1.00	0.09	0.00	0.19	0.66	0.59	0.52	0.50
714	33.33	0.00	0.00	0.00	0.92	0.00	0.00	0.02	0.73	0.73	0.00	0.00
715	36.36	0.00	0.00	0.00	0.82	0.00	0.00	0.01	0.78	0.78	0.00	0.00
811	14.29	0.07	0.00	0.00	1.14	0.00	0.00	0.08	0.78	0.00	0.54	0.00
812	8.33	0.08	0.00	0.00	1.33	0.00	0.00	0.07	0.69	0.67	0.54	0.50
813	35.71	0.00	0.00	0.00	0.71	0.00	0.00	0.03	0.90	0.90	0.00	0.00
814	20.00	0.00	0.00	0.00	1.00	0.00	0.00	0.03	0.81	0.80	0.00	0.00
815	26.32	0.00	0.00	0.00	0.84	0.00	0.00	0.37	0.92	0.88	0.00	0.00
821	37.50	0.00	0.00	0.00	0.63	0.00	0.00	0.05	1.00	0.00	0.00	0.00
822	50.00	0.00	0.00	0.00	0.61	0.00	0.00	0.20	0.86	0.82	0.00	0.00
823	53.33	0.20	0.00	0.00	0.53	0.00	0.00	0.03	0.81	0.80	1.00	0.00
824	42.86	0.00	0.00	0.00	0.57	0.00	0.00	0.14	1.00	1.00	0.00	0.00
825	36.84	0.05	0.00	0.00	0.68	0.00	0.00	0.00	0.92	0.92	1.00	0.00

[a]Number indicates site, panel, vine.

[b]LLN: leaf layer number; PIL: percent interior leaves; PIC: percent interior clusters; PG: percent gaps; OLN: occlusion layer number; CEL: cluster exposure layer; LEL: leaf exposure layer; EP1: canopy calibration coefficient; CEFA: cluster exposure flux availability; CEFA*: cluster exposure flux availability computed using dynamic calibration model; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.10 Vine canopy characteristics in mid canopy measured with EPQA mid canopy at 50 days after anthesis in 2009.

	EPQA metric[b]							
Vine[a]	PG	LLN	PIL	OLN	LEL	EP1	LEFA	LEFA*
111	7.14	1.79	8.00	1.79	0.08	0.12	0.57	0.52
112	6.67	2.07	19.35	2.07	0.19	0.16	0.51	0.45
113	21.43	1.64	26.09	1.64	0.26	0.19	0.53	0.48
114	11.76	1.35	4.35	1.35	0.04	0.13	0.69	0.65
115	0.00	2.44	22.73	2.44	0.27	0.47	0.62	0.41
121	0.00	2.36	26.92	2.36	0.27	0.08	0.45	0.42
122	22.22	1.67	20.00	1.67	0.20	0.15	0.52	0.47
123	0.00	3.13	36.00	3.13	0.40	0.13	0.32	0.32
124	10.00	2.30	26.09	2.30	0.26	0.21	0.47	0.39
125	18.18	1.27	7.14	1.27	0.07	0.08	0.67	0.64
211	0.00	3.43	41.67	3.43	0.58	0.11	0.33	0.00
212	0.00	3.11	39.29	3.11	0.46	0.09	0.35	0.32
213	0.00	3.38	40.74	3.38	0.44	0.13	0.34	0.30
214	0.00	3.38	40.74	3.38	0.41	0.13	0.34	0.30
215	0.00	2.38	21.05	2.38	0.21	0.10	0.46	0.42
221	0.00	2.67	29.17	2.67	0.29	0.21	0.46	0.00
222	0.00	2.25	14.81	2.25	0.15	0.07	0.48	0.44
223	0.00	2.75	27.27	2.75	0.27	0.19	0.44	0.36
224	0.00	2.45	25.93	2.45	0.26	0.15	0.46	0.41
225	0.00	2.82	32.26	2.82	0.35	0.06	0.38	0.35
311	11.11	2.44	27.27	2.44	0.27	0.10	0.40	0.36
312	0.00	2.50	20.00	2.50	0.20	0.19	0.48	0.40
313	18.18	1.55	11.76	1.55	0.12	0.07	0.55	0.53
314	9.09	1.64	5.56	1.64	0.06	0.05	0.58	0.56
315	0.00	1.82	5.00	1.82	0.05	0.06	0.57	0.55
321	8.33	1.25	0.00	1.25	0.00	0.19	0.78	0.73
322	10.00	1.30	0.00	1.30	0.00	0.07	0.71	0.69
323	11.11	1.67	6.67	1.67	0.07	0.15	0.60	0.53
324	0.00	1.73	5.26	1.73	0.05	0.05	0.60	0.58
325	10.00	1.70	11.76	1.70	0.12	0.23	0.62	0.53
411	0.00	2.46	25.00	2.46	0.25	0.06	0.43	0.41
412	10.00	2.30	26.09	2.30	0.26	0.05	0.41	0.39
413	0.00	2.00	5.56	2.00	0.06	0.05	0.52	0.50
414	7.14	1.57	0.00	1.57	0.00	0.02	0.60	0.59
421	12.50	2.38	31.58	2.38	0.32	0.05	0.38	0.37
422	0.00	2.07	16.13	2.07	0.16	0.04	0.50	0.48
423	6.67	1.93	13.79	1.93	0.14	0.05	0.50	0.48
424	0.00	2.27	16.00	2.27	0.16	0.06	0.46	0.44
425	7.14	1.86	11.54	1.86	0.12	0.39	0.67	0.50

511	6.25	1.63	7.69	1.63	0.08	0.13	0.62	0.58
512	0.00	2.40	20.83	2.40	0.21	0.14	0.47	0.42
513	0.00	2.00	17.86	2.00	0.18	0.09	0.53	0.50
514	7.69	2.31	26.67	2.31	0.30	0.13	0.44	0.40
515	9.09	2.36	23.08	2.36	0.23	0.14	0.44	0.38
521	7.14	1.71	12.50	1.71	0.13	0.14	0.59	0.54
522	12.50	1.63	23.08	1.63	0.23	0.02	0.54	0.54
523	0.00	2.11	15.79	2.11	0.16	0.10	0.51	0.47
524	16.67	2.67	37.50	2.67	0.41	0.25	0.40	0.31
525	0.00	2.38	19.35	2.38	0.23	0.10	0.46	0.42
611	0.00	4.25	52.94	4.25	0.68	0.19	0.29	0.24
612	0.00	4.00	50.00	4.00	0.59	0.18	0.31	0.25
613	0.00	3.13	36.00	3.13	0.40	0.16	0.38	0.32
614	0.00	3.88	48.39	3.88	0.52	0.18	0.31	0.26
615	0.00	3.40	47.06	3.40	0.62	0.16	0.34	0.29
621	18.18	1.64	16.67	1.64	0.17	0.09	0.53	0.50
622	9.09	1.91	14.29	1.91	0.14	0.08	0.51	0.48
623	12.50	1.63	19.23	1.63	0.23	0.05	0.55	0.54
624	9.09	2.18	25.00	2.18	0.25	0.10	0.45	0.42
625	8.33	1.92	13.04	1.92	0.13	0.09	0.51	0.48
711	0.00	3.44	45.16	3.44	0.48	0.20	0.35	0.00
712	0.00	3.25	38.46	3.25	0.42	0.13	0.35	0.31
713	0.00	3.11	39.29	3.11	0.46	0.18	0.38	0.32
714	0.00	3.13	36.00	3.13	0.40	0.16	0.38	0.32
715	0.00	2.56	30.43	2.56	0.30	0.17	0.45	0.39
811	0.00	2.54	30.30	2.54	0.30	0.15	0.44	0.39
812	15.38	2.77	38.89	2.77	0.42	0.11	0.34	0.31
813	0.00	2.70	25.93	2.70	0.26	0.14	0.43	0.37
814	0.00	2.70	33.33	2.70	0.37	0.13	0.41	0.37
815	0.00	1.88	23.33	2.13	0.23	0.04	0.41	0.40
821	0.00	3.58	44.19	3.58	0.53	0.29	0.38	0.28
822	7.69	2.54	36.36	2.54	0.48	0.20	0.43	0.36
823	0.00	3.00	33.33	3.00	0.33	0.15	0.39	0.33
824	0.00	2.89	30.77	2.89	0.35	0.16	0.41	0.35
825	0.00	1.63	15.38	1.81	0.15	0.08	0.53	0.50

[a]Number indicates site, panel, vine.

[b]PG: percent gaps; LLN: leaf layer number; PIL: percent interior leaves OLN: occlusion layer number; LEL: leaf exposure layer; EP1: canopy calibration coefficient; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.11 Vine canopy characteristics in mid canopy measured with EPQA at harvest in 2009.

	EPQA metric[b]							
Site[a]	**PG**	**LLN**	**PIL**	**OLN**	**LEL**	**EP1**	**LEFA**	**LEFA***
111	0.00	1.90	5.26	1.90	0.05	0.14	0.58	0.53
112	0.00	1.79	12.00	1.79	0.12	0.12	0.60	0.56
113	15.38	1.69	18.18	1.69	0.18	0.20	0.57	0.50
114	0.00	1.54	5.00	1.54	0.05	0.17	0.70	0.65
115	0.00	2.09	8.70	2.09	0.09	0.42	0.67	0.48
121	16.67	1.33	6.25	1.33	0.06	0.01	0.63	0.63
122	18.18	1.82	20.00	1.82	0.20	0.17	0.52	0.45
123	0.00	2.09	13.04	2.09	0.13	0.07	0.47	0.48
124	22.22	1.44	15.38	1.44	0.15	0.08	0.56	0.54
125	0.00	1.38	0.00	1.38	0.00	0.10	0.75	0.73
211	0.00	3.00	40.00	3.00	0.50	0.08	0.36	0.00
212	0.00	2.89	34.62	2.89	0.38	0.07	0.37	0.35
213	0.00	2.44	22.73	2.44	0.23	0.06	0.43	0.41
214	0.00	2.38	19.35	2.38	0.19	0.05	0.44	0.42
215	0.00	1.82	10.00	1.82	0.10	0.05	0.57	0.55
221	18.18	1.73	26.32	1.73	0.26	0.09	0.50	0.00
222	0.00	2.00	18.18	2.00	0.18	0.05	0.52	0.50
223	0.00	1.89	5.88	1.89	0.06	0.09	0.57	0.53
224	0.00	2.50	20.00	2.50	0.20	0.16	0.47	0.40
225	12.50	2.50	30.00	2.50	0.30	0.04	0.37	0.35
311	9.09	2.18	29.17	2.18	0.29	0.07	0.44	0.42
312	27.27	1.73	26.32	1.73	0.26	0.09	0.45	0.42
313	10.00	1.70	5.88	1.70	0.06	0.08	0.56	0.53
314	7.69	1.69	9.09	1.69	0.09	0.06	0.57	0.55
315	22.22	1.56	7.14	1.56	0.07	0.04	0.52	0.50
321	10.00	1.20	0.00	1.20	0.00	0.03	0.76	0.75
322	8.33	1.33	0.00	1.42	0.00	0.06	0.65	0.63
323	10.00	1.70	11.76	1.70	0.12	0.07	0.56	0.53
324	8.33	1.50	5.56	1.50	0.06	0.04	0.63	0.61
325	20.00	1.20	8.33	1.20	0.08	0.03	0.67	0.67
411	0.00	2.50	26.67	2.50	0.27	0.11	0.44	0.40
412	0.00	3.31	39.53	3.31	0.42	0.27	0.40	0.30
413	0.00	2.30	21.74	2.30	0.22	0.16	0.50	0.43
414	0.00	1.93	17.24	1.93	0.17	0.18	0.58	0.52
421	0.00	3.08	35.14	3.08	0.38	0.27	0.43	0.32
422	0.00	2.57	27.78	2.57	0.28	0.19	0.46	0.39
423	0.00	3.00	35.90	3.00	0.38	0.31	0.45	0.33
424	0.00	2.64	24.14	2.64	0.24	0.21	0.47	0.38

425	0.00	2.82	30.74	2.82	0.32	0.25	0.45	0.36
511	6.67	2.07	22.58	2.07	0.23	0.21	0.53	0.45
512	0.00	2.80	32.14	2.80	0.32	0.17	0.42	0.36
513	7.69	2.31	26.67	2.31	0.27	0.15	0.45	0.40
514	0.00	2.80	32.14	2.80	0.32	0.21	0.44	0.36
515	0.00	3.00	36.67	3.00	0.40	0.26	0.43	0.33
521	0.00	2.71	30.43	2.82	0.33	0.32	0.49	0.36
522	0.00	2.50	20.00	2.50	0.20	0.26	0.52	0.40
523	0.00	2.62	29.41	2.62	0.29	0.20	0.46	0.38
524	0.00	2.50	27.50	2.50	0.30	0.19	0.47	0.40
525	0.00	2.60	23.08	2.60	0.23	0.19	0.47	0.38
611	0.00	4.25	52.94	4.25	0.68	0.19	0.29	0.24
612	0.00	4.00	50.00	4.00	0.59	0.18	0.31	0.25
613	0.00	3.13	36.00	3.13	0.40	0.16	0.38	0.32
614	0.00	3.88	48.39	3.88	0.52	0.18	0.31	0.26
615	0.00	3.40	47.06	3.40	0.62	0.16	0.34	0.29
621	18.18	1.64	16.67	1.64	0.17	0.09	0.53	0.50
622	9.09	1.91	14.29	1.91	0.14	0.08	0.51	0.48
623	12.50	1.63	19.23	1.63	0.23	0.05	0.55	0.54
624	9.09	2.18	25.00	2.18	0.25	0.10	0.45	0.42
625	8.33	1.92	13.04	1.92	0.13	0.09	0.51	0.48
711	0.00	2.92	31.43	2.92	0.31	0.15	0.40	0.00
712	0.00	3.00	36.36	3.00	0.42	0.11	0.37	0.33
713	0.00	2.33	17.86	2.33	0.18	0.10	0.47	0.43
714	0.00	2.46	25.00	2.46	0.25	0.10	0.44	0.41
715	0.00	3.50	42.86	3.50	0.50	0.27	0.38	0.29
811	8.33	2.33	28.57	2.33	0.29	0.13	0.44	0.39
812	0.00	2.75	27.27	2.75	0.30	0.11	0.41	0.31
813	0.00	2.30	21.74	2.30	0.22	0.10	0.47	0.37
814	0.00	3.17	36.84	3.17	0.37	0.17	0.38	0.37
815	0.00	3.00	33.33	3.00	0.36	0.10	0.37	0.40
821	0.00	2.67	31.25	2.67	0.38	0.19	0.44	0.28
822	0.00	2.36	18.18	2.36	0.18	0.18	0.50	0.36
823	15.38	2.23	27.59	2.23	0.28	0.08	0.41	0.33
824	0.00	2.77	27.78	2.77	0.28	0.15	0.42	0.35
825	0.00	1.94	19.35	2.13	0.19	0.11	0.47	0.50

[a]Number indicates site, panel, vine.

[b]PG: percent gaps; LLN: leaf layer number; PIL: percent interior leaves OLN: occlusion layer number; LEL: leaf exposure layer; EP1: canopy calibration coefficient; LEFA: leaf exposure flux availability; LEFA leaf exposure flux availability computed using dynamic calibration model.

Appendix 3.12 $\delta^{13}C$ in leaves and berries in 2008.

	$\delta^{13}C$ ($^{0}/_{00}$)			
	Leaves		Berries	
Vine[a]	50 Days after anthesis	Harvest	50 Days after anthesis	Harvest
111	-28.71	-29.82	-28.91	-28.64
112	-28.63	-29.58	-29.08	-27.99
113	-29.06	-30.09	-28.71	-28.63
114	-28.94	-30.19	-29.02	-28.62
115	-28.96	-29.61	-29.09	-28.63
121	-29.12	-29.51	-28.39	-28.44
122	-29.28	-30.08	-28.41	-28.26
123	-28.78	-29.72	-28.78	-28.56
124	-28.47	-29.39	-28.77	-27.81
125	-29.47	-29.17	-28.47	-28.34
211	-28.25	-28.07	-27.80	-27.60
212	-28.77	-29.29	-27.68	-26.43
213	-28.62	-29.42	-26.98	-27.21
214	-28.57	-29.40	-29.24	-27.26
215	-28.13	-28.15	-27.80	-26.66
221	-28.62	-29.18	-27.96	-28.16
222	-28.89	-29.70	-27.80	-28.25
223	-29.10	-29.51	-28.35	-27.97
224	-28.35	-29.65	-28.93	-28.47
225	-28.99	-29.01	-28.58	-28.36
311	-29.56	-29.62	-29.18	-27.19
312	-29.76	-29.61	-28.43	-26.74
313	-29.94	-29.21	-28.17	-26.96
314	-29.73	-30.17	-28.51	-27.67
315	-29.45	-29.85	-28.61	-27.62
321	-29.45	-29.25	-27.89	-27.04
322	-28.43	-28.43	-27.41	-26.46
323	-28.71	-28.68	-28.97	-25.91
324	-28.92	-29.24	-26.88	-26.17
325	-29.24	-30.18	-28.01	-27.69
411	-28.48	-29.03	-27.06	-27.19
412	-28.65	-29.20	-27.13	-27.61
413	-28.40	-28.91	-27.83	-27.77
414	-28.34	-29.18	-27.81	-27.17
415	-28.85	-29.61	-27.92	-27.10
421	-28.59	-29.00	-27.43	-27.15
422	-28.64	-28.79	-27.91	-26.90

423	-29.10	-29.06	-27.74	-26.97
424	-28.64	-29.10	-27.96	-27.18
425	-28.64	-29.05	-27.92	-27.09
511	-29.05	-28.45	-28.10	-26.67
512	-28.75	-26.70	-27.46	-25.59
513	-27.83	-29.42	-27.95	-26.88
514	-28.35	-28.69	-28.36	-27.15
515	-27.70	-29.39	-27.69	-26.85
521	-28.34	-28.85	-27.95	-26.67
522	-28.51	-28.86	-28.42	-26.81
523	-28.16	-29.13	-28.30	-26.27
524	-29.03	-28.41	-27.74	-26.05
525	-28.24	-28.84	-28.44	-27.13
611	-27.85	-28.20	-27.02	-26.80
612	-27.55	-28.14	-27.17	-26.36
613	-28.17	-28.15	-27.27	-26.46
614	-28.08	-27.84	-26.84	-26.36
615	-27.71	-27.98	-27.63	-25.57
621	-28.91	-29.60	-27.73	-27.67
622	-28.96	-29.01	-27.69	-27.61
623	-29.17	-29.74	-27.12	-27.81
624	-28.47	-29.85	-27.43	-27.59
625	-27.94	-29.55	-27.71	-27.26
711	-28.81	-29.65	-27.79	-28.16
712	-29.17	-29.73	-28.11	-27.74
713	-29.89	-29.78	-28.03	-28.00
714	-28.74	-29.32	-27.92	-28.02
715	-29.20	-28.76	-27.89	-28.01
721	-28.96	-29.68	-28.32	-28.05
722	-29.80	-29.85	-28.72	-27.89
723	-28.95	-29.19	-28.38	-28.17
724	-29.00	-29.55	-28.09	-27.78
725	-29.26	-29.31	-27.86	-28.11
731	-28.84	-29.47	-29.10	-27.96
732	-28.64	-29.80	-28.43	-28.02
733	-28.34	-29.61	-28.03	-27.61
734	-28.05	-29.60	-27.66	-27.68
735	-28.63	-29.60	-27.92	-28.52
811	-27.87	-29.76	-28.45	-28.53
812	-28.61	-29.99	-27.96	-26.82
813	-29.05	-29.48	-26.80	-27.91
814	-29.35	-29.37	-27.34	-27.57
815	-28.16	-29.83	-28.18	-28.01
821	-27.55	-30.37	-28.44	-28.54

822	-27.95	-30.67	-28.73	-28.26
823	-27.85	-30.37	-28.75	-28.06
824	-27.55	-30.14	-28.45	-28.46
825	-28.17	-30.50	-28.78	-28.52
911	-29.41	-29.93	-28.62	-27.85
912	-29.58	-30.44	-28.81	-27.95
913	-29.91	-30.61	-28.35	-28.35
914	-30.09	-30.47	-28.99	-28.13
915	-30.32	-30.30	-28.20	-28.43
921	-28.55	-28.75	-28.51	-26.81
922	-29.39	-29.24	-28.31	-26.64
923	-29.35	-29.99	-28.49	-26.33
924	-28.78	-29.55	-28.47	-26.33
925	-29.45	-29.29	-28.04	-25.80
1011	-28.29	-28.75	-26.75	-26.96
1012	-28.22	-28.59	-26.96	-26.97
1013	-28.38	-28.37	-26.90	-27.41
1014	-29.18	-28.66	-27.18	-27.08
1015	-28.88	-28.04	-26.54	-26.89
1021	-28.90	-28.97	-26.77	-27.32
1022	-28.85	-29.19	-27.43	-26.89
1023	-28.93	-29.19	-27.35	-26.66
1024	-28.29	-29.52	-26.75	-28.07
1025	-28.47	-29.51	-28.19	-27.79

[a]Number indicates site, panel, vine.

Appendix 3.13 $\delta^{13}C$ in leaves and berries in 2009.

Vine[a]	$\delta^{13}C$ ($^0/_{00}$) Leaves 50 Days after anthesis	Leaves Harvest	Berries 50 Days after anthesis	Berries Harvest
111	-30.66	-29.26	-28.64	-28.58
112	-29.71	-28.20	-27.93	-27.86
113	-31.37	-29.46	-28.09	-28.40
114	-30.68	-28.73	-28.03	-28.15
115	-30.75	-29.70	-28.68	-28.58
121	-30.85	-28.76	-27.85	-28.40
122	-30.54	-28.28	-27.84	-28.54
123	-30.36	-29.30	-27.93	-28.13
124	-29.42	-29.18	-27.98	-28.10
125	-29.47	-28.73	-28.13	-28.21
211	-28.53	-27.72	-26.88	-26.91
212	-28.96	-27.03	-26.79	-27.36
213	-29.57	-28.25	-27.50	-28.12
214	-28.84	-27.80	-26.81	-27.12
215	-28.79	-26.99	-26.43	-27.25
221	-29.60	-28.47	-27.61	-27.93
222	-29.59	-28.76	-27.75	-27.67
223	-29.38	-27.55	-27.84	-27.84
224	-29.87	-28.13	-27.54	-27.97
225	-29.47	-28.21	-27.45	-27.94
311	-30.15	-28.99	-28.18	-29.47
312	-30.95	-29.11	-27.05	-28.86
313	-30.59	-29.12	-27.90	-29.02
314	-30.60	-29.68	-28.37	-28.92
315	-30.47	-28.39	-28.90	-29.13
321	-30.43	-28.70	-26.22	-29.26
322	-30.14	-29.10	-26.75	-27.91
323	-29.42	-28.44	-26.56	-27.87
324	-30.17	-28.45	-26.44	-28.72
325	-30.09	-28.90	-26.06	-29.48
411	-29.37	-27.60	-26.28	-27.48
412	-29.01	-28.14	-26.33	-27.78
413	-28.93	-27.23	-26.38	-27.67
414	-29.24	-27.07	-25.94	-27.74
421	-29.89	-28.01	-26.14	-27.34
422	-29.01	-28.25	-26.23	-26.25
423	-29.20	-27.29	-26.55	-27.48
424	-29.08	-27.66	-26.59	-27.22

425	-28.45	-27.30	-25.89	-26.59
511	-28.57	-27.35	-26.03	-26.75
512	-28.36	-27.22	-26.19	-26.56
513	-28.44	-27.19	-26.05	-27.04
514	-28.94	-27.53	-26.93	-27.04
515	-28.69	-27.42	-27.19	-26.73
521	-28.38	-27.30	-27.23	-26.52
522	-28.46	-27.64	-27.26	-26.75
523	-27.80	-27.71	-26.94	-26.72
524	-28.53	-27.34	-27.12	-26.83
525	-28.14	-27.41	-27.16	-27.53
611	-28.86	-27.87	-27.68	-27.44
612	-28.97	-28.08	-27.57	-28.12
613	-29.49	-27.13	-27.66	-27.85
614	-28.79	-27.33	-27.53	-27.73
615	-28.98	-27.77	-27.39	-28.05
621	-28.78	-28.68	-27.19	-27.93
622	-28.83	-28.02	-27.08	-27.96
623	-28.98	-27.60	-27.41	-27.73
624	-28.34	-27.92	-26.83	-27.43
625	-29.05	-27.97	-27.47	-27.58
711	-29.54	-28.60	-28.28	-27.33
712	-29.94	-28.55	-27.80	-28.39
713	-28.94	-27.75	-28.03	-28.06
714	-28.79	-29.16	-27.86	-28.05
715	-29.50	-27.83	-28.20	-28.53
811	-28.64	-29.48	-26.88	-28.13
812	-29.37	-29.56	-27.25	-27.58
813	-29.12	-28.58	-28.00	-27.69
814	-29.01	-29.06	-27.28	-28.09
815	-29.83	-29.15	-28.00	-27.84
821	-30.00	-29.43	-27.79	-28.00
822	-30.45	-29.93	-28.17	-27.10
823	-30.65	-29.47	-28.05	-27.78
824	-28.78	-30.03	-27.27	-26.68
825	-30.04	-29.34	-28.14	-27.56

[a]Number indicates site, panel, vine.

Appendix 3.14 Vine characteristics at harvest and cropload in 2008.

Vine[a]	Vine characteristics at harvest					Crop load
	Shoots/vine[b]	Shoots/m[c]	Cane weight (g)	Pruning weight (kg)	Periderm[d]	Yield/pruning weight (kg)
111	31	19.4	2.18	60.4	14.0	0.5
112	17	10.6	0.21	17.1	13.7	3.5
113	34	21.3	1.77	63.1	12.7	1.3
114	31	19.4	1.79	66.3	9.3	0.8
115	23	14.4	0.69	32.9	9.2	0.5
121	15	9.4	0.28	20.3	10.5	3.9
122	33	20.6	0.38	21.0	13.2	0.6
123	24	15.0	1.18	34.8	10.2	0.7
124	22	13.8	1.61	47.4	13.1	1.4
125	34	21.3	0.93	38.9	11.2	1.8
211	48	26.7	0.90	29.9	7.0	12.0
212	48	26.7	0.91	26.6	7.6	7.9
213	42	23.3	1.18	39.3	8.7	8.9
214	56	31.1	1.02	36.3	9.0	9.4
215	48	26.7	1.03	36.7	8.9	7.9
221	37	20.6	0.93	24.4	6.0	9.8
222	38	21.1	1.68	44.2	10.3	5.1
223	34	18.9	2.21	66.9	9.6	4.2
224	32	17.8	1.51	34.3	8.4	6.5
225	32	17.8	1.43	39.6	9.1	6.9
311	37	21.8	1.14	38.1	8.7	5.8
312	37	21.8	1.07	34.4	11.3	5.1
313	37	21.8	0.78	26.2	7.7	8.0
314	30	17.6	0.58	19.2	7.4	10.5
315	35	20.6	1.04	40.0	6.3	6.2
321	38	22.4	0.25	11.2	5.3	20.4
322	39	22.9	0.12	12.3	4.5	48.8
323	38	22.4	0.26	11.7	6.0	27.6
324	38	22.4	0.55	36.5	6.2	10.4
325	34	20.0	0.29	14.7	7.4	22.6
411	42	9.5	0.81	24.6	11.0	15.9
412	37	8.4	0.94	32.2	11.4	13.1
413	36	8.2	1.78	63.5	11.8	6.3
414	38	8.6	1.14	39.2	10.6	7.6
415	48	10.9	1.20	30.8	7.7	9.2
421	45	10.2	1.19	38.5	16.5	7.5
422	45	10.2	1.60	50.0	13.9	6.6
423	46	10.5	1.93	62.4	14.3	6.0

424	40	9.1	1.17	40.4	11.8	8.6
425	46	10.5	1.52	46.2	12.5	7.7
511	26	11.8	1.58	60.9	11.8	2.9
512	22	10.0	1.52	69.3	15.5	2.9
513	30	13.6	1.97	65.6	11.3	3.0
514	33	15.0	1.20	36.3	11.9	5.5
515	24	10.9	1.32	55.0	15.3	4.6
521	38	8.6	2.07	54.5	15.4	3.2
522	46	10.5	2.25	48.9	9.2	4.1
523	27	12.3	2.11	78.2	10.2	1.9
524	38	8.6	1.76	46.2	16.3	4.6
525	48	10.9	2.26	47.1	13.8	4.0
611	33	15.0	0.65	29.5	14.1	6.0
612	38	8.6	1.13	40.2	12.4	4.6
613	36	16.4	0.69	29.9	18.9	4.7
614	30	13.6	0.59	29.4	16.7	4.9
615	31	9.1	0.64	31.9	13.4	4.5
621	35	10.3	0.88	38.0	11.1	9.2
622	44	12.9	0.93	33.0	10.6	7.8
623	45	13.2	1.01	32.7	10.0	11.3
624	51	15.0	1.50	45.5	10.4	8.3
625	49	14.4	1.14	24.3	10.2	9.2
711	20	13.3	1.51	83.9	13.7	2.4
712	21	14.0	1.15	60.6	12.9	2.4
713	31	20.7	1.32	45.4	10.8	1.9
714	20	13.3	1.49	82.6	14.0	2.6
715	22	14.7	1.81	86.2	13.6	2.0
721	34	18.9	0.64	19.9	11.4	6.9
722	24	13.3	0.80	33.4	12.6	2.9
723	30	16.7	1.73	57.8	11.5	1.5
724	32	17.8	0.82	25.6	12.8	4.3
725	29	16.1	1.82	62.8	13.5	2.1
811	27	15.0	1.15	50.0	12.2	1.2
812	26	14.4	1.03	46.8	10.2	1.3
813	25	13.9	0.83	39.5	11.5	1.4
814	26	14.4	1.20	54.5	11.8	0.9
815	24	13.3	1.36	68.0	11.7	0.6
821	29	15.3	1.80	69.3	14.0	1.3
822	34	17.9	1.69	60.5	13.7	1.6
823	33	17.4	1.90	76.0	14.0	1.0
824	29	15.3	1.69	80.4	12.9	1.0
825	36	18.9	2.06	76.2	12.4	1.2
911	28	14.7	2.34	86.6	12.9	0.8
912	30	15.8	2.86	89.5	13.2	0.7

913	27	14.2	1.95	62.8	13.0	0.9
914	23	12.1	2.33	86.3	14.0	1.2
915	29	15.3	2.02	65.1	13.4	1.4
921	36	25.7	0.78	21.7	7.9	7.7
922	31	22.1	0.18	8.2	6.5	17.3
923	39	27.9	0.30	10.0	3.3	27.4
924	35	25.0	0.42	16.2	6.2	10.2
925	27	19.3	0.22	12.2	4.9	10.4
931	33	23.6	0.19	7.9	5.9	16.6
932	35	25.0	0.18	6.9	3.6	14.4
933	19	13.6	0.34	20.0	5.9	18.2
934	31	22.1	0.39	14.4	6.1	9.7
935	36	25.7	0.37	14.8	6.8	16.1
1011	40	21.1	0.36	17.1	8.5	7.4
1012	41	21.6	0.47	22.4	6.4	9.0
1013	30	15.8	0.09	5.6	5.5	16.7
1014	44	23.2	0.40	13.8	6.2	13.1
1015	50	26.3	0.35	11.3	8.2	9.6
1021	34	17.9	0.15	8.3	7.2	12.0
1022	33	17.4	0.37	24.7	9.0	2.9
1023	58	30.5	0.25	10.9	11.0	9.1
1024	39	20.5	0.16	11.4	9.1	11.8
1025	33	17.4	0.16	16.0	7.2	6.4

[a]Number indicates site, panel, vine.
[b]Count shoots.
[c]Counts shoots.
[d]Number of internodes with ripe periderm.

Appendix 3.15 Vine characteristics at harvest and cropload in 2009.

Vine [a]	Vine characteristics at harvest: Shoots/vine [b]	Shoot/m [c]	Cane weight (g)	Pruning weight (kg)	Periderm [d]	Crop load: Yield / pruning weight (kg)
111	23	14.38	36.3	0.69	7.00	3.19
112	24	15.00	36.0	0.72	8.05	3.78
113	28	17.50	35.0	0.84	5.32	2.04
114	30	18.75	34.6	0.90	7.05	2.58
115	21	13.13	37.1	0.63	7.38	0.67
121	23	14.38	36.3	0.69	6.08	3.95
122	28	17.50	35.0	0.84	4.60	1.69
123	19	11.88	38.0	0.57	3.77	3.38
124	14	8.75	42.0	0.42	7.14	2.04
125	10	6.25	50.0	0.30	3.20	0.91
211	25	13.89	74.3	1.56	13.42	1.65
212	24	13.33	72.0	1.44	9.50	2.24
213	26	14.44	47.7	1.05	8.33	3.42
214	24	13.33	63.5	1.27	9.82	3.75
215	18	10.00	57.1	0.80	13.17	3.91
221	19	10.56	57.3	0.86	12.25	3.17
222	16	8.89	64.2	0.77	12.22	3.86
223	22	12.22	71.7	1.29	11.60	3.10
224	23	12.78	67.4	1.28	12.08	3.28
225	18	10.00	87.1	1.22	10.60	2.91
311	33	19.41	34.1	0.99	6.19	4.10
312	29	17.06	34.8	0.87	10.43	5.32
313	33	19.41	34.1	0.99	7.18	5.46
314	32	18.82	34.3	0.96	6.42	4.50
315	30	17.65	34.6	0.90	8.65	4.36
321	24	14.12	13.5	0.27	5.00	6.44
322	19	11.18	40.0	0.60	9.13	3.60
323	23	13.53	27.9	0.53	11.21	2.26
324	38	22.35	29.1	0.99	6.20	5.41
325	32	18.82	14.3	0.40	3.42	10.60
411	35	7.95	62.4	2.06	11.32	5.10
412	36	8.18	65.3	2.22	12.46	4.35
413	26	5.91	90.4	2.17	12.07	3.10
414	33	7.50	53.9	1.67	12.00	7.05
415	32	7.27	95.3	2.86	12.00	3.12
421	30	6.82	69.6	1.95	12.43	4.57
422	28	6.36	88.1	2.29	14.09	3.32
423	28	6.36	77.3	2.01	11.82	4.75
424	27	6.14	100.4	2.51	13.67	2.61
511	36	8.18	65.6	2.23	13.08	5.30
512	19	8.64	105.9	1.80	13.75	2.83
513	33	7.50	80.0	2.48	12.36	4.58

514	27	12.27	64.8	1.62	13.56	3.91
515	18	8.18	127.0	2.03	14.13	1.73
521	25	11.36	148.7	3.42	12.43	1.36
522	34	7.73	69.1	2.21	14.00	3.58
523	21	9.55	64.7	1.23	13.38	2.76
524	19	8.64	70.0	1.19	12.73	4.46
525	35	7.95	79.1	2.61	13.47	3.25
611	22	6.47	63.6	1.27	11.89	1.87
612	30	8.82	77.6	2.17	9.52	1.60
613	28	8.24	53.5	1.39	10.20	2.39
614	21	6.18	56.8	1.08	11.73	1.84
615	33	9.71	37.9	1.18	7.48	2.47
621	19	11.18	79.8	1.36	8.08	2.74
622	18	10.59	64.5	1.03	13.79	2.98
623	18	10.59	86.3	1.38	14.56	2.98
624	23	13.53	94.4	2.17	14.75	2.12
625	23	13.53	40.7	0.94	10.25	3.45
711	24	13.33	49.5	0.99	13.40	2.92
712	23	12.78	51.1	0.97	8.80	2.87
713	21	11.67	44.7	0.76	11.50	4.45
714	23	12.78	52.1	0.99	14.00	2.93
715	19	10.56	73.3	1.10	10.38	2.35
811	21	11.05	82.1	1.56	11.50	2.55
812	25	13.16	74.8	1.72	9.40	2.41
813	22	11.58	98.5	1.97	12.70	0.82
814	26	13.68	80.0	1.92	13.70	2.10
815	20	10.53	87.2	1.57	14.80	1.61
821	16	8.42	127.5	2.04	9.00	0.58
822	18	9.47	139.4	2.51	14.60	0.40
823	18	9.47	97.2	1.75	12.80	0.15
824	18	9.47	128.3	2.31	11.50	0.63
825	15	7.89	102.0	1.53	14.50	0.54

[a]Number indicates site, panel, vine.
[b]Count shoots.
[c]Count shoots.
[d]Number of internodes with ripe periderm.

Appendix 3.16 Yield components in 2008.

Vine[a]	Harvest Parameters				
	Fresh berry weight (g)	% Berry dry weight	Clusters #	Cluster weight (g)	Yield (kg)
111	1.96	0.26	8	125.0	1.00
112	1.40	0.26	6	120.0	0.72
113	1.73	0.25	22	101.8	2.24
114	1.81	0.26	12	116.7	1.40
115	1.96	0.23	4	90.0	0.36
121	1.44	0.27	8	137.5	1.10
122	1.33	0.25	2	120.0	0.24
123	1.58	0.25	5	172.0	0.86
124	1.59	0.24	12	193.3	2.32
125	1.63	0.25	11	156.4	1.72
211	1.46	0.22	89	120.9	10.76
212	1.38	0.23	77	93.2	7.18
213	1.28	0.23	80	131.8	10.54
214	1.49	0.24	84	114.0	9.58
215	1.37	0.22	69	117.7	8.12
221	1.34	0.24	83	109.2	9.06
222	1.41	0.26	88	97.0	8.54
223	1.32	0.27	83	111.8	9.28
224	1.28	0.23	101	97.4	9.84
225	1.32	0.26	89	110.8	9.86
311	1.37	0.27	76	87.6	6.66
312	1.65	0.27	62	87.4	5.42
313	1.43	0.25	85	73.6	6.26
314	1.43	0.27	66	91.5	6.04
315	1.46	0.25	83	77.1	6.40
321	1.25	0.21	79	63.5	5.02
322	1.24	0.23	82	72.9	5.98
323	1.28	0.23	73	97.3	7.10
324	1.27	0.26	71	80.0	5.68
325	1.47	0.25	72	92.5	6.66
411	1.51	0.24	58	222.8	12.92
412	1.54	0.23	56	219.3	12.28
413	1.57	0.23	56	199.6	11.18
414	1.75	0.25	41	211.7	8.68
415	1.54	0.24	54	204.1	11.02
421	1.60	0.27	46	194.3	8.94
422	1.55	0.24	60	175.3	10.52
423	1.70	0.24	63	184.8	11.64
424	1.62	0.24	47	213.6	10.04

425	1.55	0.25	59	199.0	11.74
511	1.59	0.27	26	176.2	4.58
512	1.84	0.26	24	185.8	4.46
513	1.47	0.27	28	212.9	5.96
514	1.78	0.27	30	220.7	6.62
515	1.70	0.26	26	232.3	6.04
521	1.31	0.26	41	163.4	6.70
522	1.27	0.26	54	172.2	9.30
523	1.36	0.28	32	126.3	4.04
524	1.42	0.27	42	191.4	8.04
525	1.41	0.27	52	173.8	9.04
611	1.39	0.24	42	92.4	3.88
612	1.24	0.26	53	98.1	5.20
613	1.35	0.26	31	104.5	3.24
614	1.34	0.27	34	84.7	2.88
615	1.28	0.26	34	84.1	2.86
621	1.38	0.26	64	125.6	8.04
622	1.53	0.26	59	123.1	7.26
623	1.35	0.23	68	168.2	11.44
624	1.54	0.24	82	152.2	12.48
625	1.66	0.26	83	127.1	10.55
711	1.54	0.24	10	366.0	3.66
712	1.51	0.24	16	170.0	2.72
713	1.53	0.24	13	192.3	2.50
714	1.70	0.24	13	295.4	3.84
715	1.64	0.24	11	330.9	3.64
721	1.70	0.25	28	155.7	4.36
722	1.67	0.25	15	153.3	2.30
723	1.56	0.25	18	143.3	2.58
724	1.68	0.25	27	131.1	3.54
725	1.70	0.26	23	166.1	3.82
811	1.74	0.24	23	61.7	1.42
812	1.44	0.25	20	65.0	1.30
813	1.63	0.25	22	53.6	1.18
814	1.59	0.25	19	57.9	1.10
815	1.73	0.24	21	41.0	0.86
821	1.67	0.25	15	156.0	2.34
822	2.01	0.25	25	110.4	2.76
823	1.66	0.25	16	113.8	1.82
824	1.74	0.26	13	127.7	1.66
825	1.75	0.25	21	115.2	2.42
911	1.83	0.22	15	120.0	1.80
912	1.65	0.26	18	112.2	2.02
913	1.79	0.26	19	88.4	1.68

914	1.83	0.23	20	134.0	2.68
915	1.61	0.27	26	106.9	2.78
921	1.50	0.24	73	82.2	6.00
922	1.26	0.23	44	70.9	3.12
923	1.57	0.24	63	130.5	8.22
924	1.42	0.25	64	66.9	4.28
925	1.38	0.24	35	65.1	2.28
931	1.30	0.24	36	87.8	3.16
932	1.07	0.23	39	66.7	2.60
933	1.12	0.22	91	68.1	6.20
934	1.38	0.22	57	66.7	3.80
935	1.23	0.23	69	86.1	5.94
1011	1.48	0.22	43	61.9	2.66
1012	1.28	0.23	65	65.2	4.24
1013	0.98	0.22	41	36.6	1.50
1014	1.10	0.22	73	71.5	5.22
1015	1.27	0.22	57	58.9	3.36
1021	1.36	0.25	42	42.9	1.80
1022	1.37	0.25	21	50.5	1.06
1023	1.67	0.24	31	73.5	2.28
1024	1.31	0.25	47	40.0	1.88
1025	1.17	0.25	35	29.1	1.02

[a]Number indicates site, panel, vine.

Appendix 3.17 Yield components in 2009.

Vine[a]	Berry weight (g)			Harvest Parameters		
	30 DAA	50 DAA	Harvest	Yield (kg)	Clusters #	Cluster weight (g)
111	0.08	1.01	1.01	2.20	34	64.7
112	0.10	1.15	1.30	2.72	40	68.0
113	0.11	0.97	1.22	1.72	36	47.7
114	0.10	0.97	1.07	2.32	38	61.1
115	0.11	0.91	1.18	0.42	12	35.3
121	0.18	1.12	1.27	2.73	31	88.0
122	0.11	0.99	1.20	1.42	36	39.4
123	0.10	0.94	1.10	1.93	23	83.8
124	0.10	1.06	1.11	0.85	12	71.2
125	0.08	0.59	0.99	0.27	7	39.0
211	0.27	0.68	1.28	2.57	32	80.3
212	0.25	0.59	1.17	3.23	38	85.0
213	0.22	0.58	1.21	3.59	48	74.8
214	0.28	0.67	1.28	4.76	54	88.1
215	0.27	0.61	1.32	3.13	32	97.8
221	0.26	0.56	1.07	2.73	31	88.1
222	0.19	0.62	1.12	2.97	26	114.2
223	0.22	0.59	1.12	4.00	39	102.6
224	0.26	0.51	1.11	4.20	36	116.7
225	0.21	0.62	1.18	3.55	42	84.5
311	0.23	1.04	1.17	4.06	66	61.5
312	0.34	0.94	1.20	4.63	72	64.3
313	0.28	0.87	1.07	5.41	91	59.5
314	0.22	0.73	1.19	4.32	74	58.4
315	0.23	0.78	1.22	3.92	71	55.2
321	0.16	0.61	0.90	1.74	29	60.0
322	0.16	0.58	1.03	2.16	31	69.7
323	0.15	0.56	1.09	1.20	25	48.0
324	0.25	0.59	1.02	5.36	98	54.7
325	0.25	0.62	1.12	4.24	90	47.1
411	0.43	0.87	1.47	10.51	73	144.0
412	0.35	0.83	1.52	9.65	70	137.9
413	0.38	0.94	1.60	6.72	50	134.4
414	0.44	0.94	1.47	11.77	76	154.9
421	0.36	0.88	1.54	8.92	57	156.5
422	0.34	0.86	1.57	8.92	55	162.2
423	0.38	0.80	1.52	7.60	48	158.3
424	0.40	0.80	1.40	9.55	60	159.2
425	0.40	0.87	1.55	6.55	45	145.6

511	0.39	0.81	1.32	11.81	77	153.4
512	0.41	0.81	1.26	5.09	37	137.6
513	0.40	0.79	1.28	11.37	72	157.9
514	0.38	0.87	1.26	6.34	47	134.9
515	0.38	0.86	1.35	3.52	27	130.4
521	0.39	0.83	1.37	4.65	39	119.2
522	0.35	0.77	1.37	7.92	62	127.7
523	0.31	0.84	1.38	3.39	28	121.1
524	0.30	0.76	1.18	5.31	41	129.5
525	0.44	0.81	1.24	8.48	64	132.3
611	0.41	0.83	1.53	2.38	24	99.2
612	0.48	0.81	1.59	3.47	36	96.3
613	0.44	0.73	1.54	3.33	19	175.1
614	0.39	0.97	1.61	1.99	32	62.1
615	0.43	0.96	1.68	2.90	31	93.5
621	0.38	0.78	1.60	3.72	46	80.9
622	0.42	0.96	1.78	3.08	31	99.3
623	0.37	0.81	1.54	4.11	37	111.1
624	0.40	0.78	1.53	4.61	43	107.3
625	0.39	0.85	1.36	3.22	31	104.0
711	0.52	0.92	1.53	2.89	36	80.3
712	0.50	0.97	1.58	2.78	35	79.4
713	0.53	0.98	1.70	3.38	39	86.7
714	0.52	0.97	1.52	2.90	31	93.5
715	0.49	1.00	1.76	2.59	27	95.9
811	0.62	1.10	1.83	3.98	28	142.1
812	0.66	1.09	1.52	4.14	29	142.8
813	0.63	1.07	1.73	1.62	17	95.3
814	0.57	1.13	1.63	4.04	23	175.7
815	0.70	1.16	1.61	2.52	26	96.9
821	0.65	1.24	1.69	1.19	11	108.2
822	0.71	1.13	1.58	1.01	13	77.7
823	0.72	1.00	1.92	0.26	6	43.3
824	0.60	1.24	1.66	1.46	19	76.8
825	0.65	1.04	1.74	0.83	11	75.5

[a]Number indicates site, panel, vine.

Appendix 3.18 Berry chemistry and classic maturity indices in 2008.

Vine[a]	Grape chemical parameters and classic maturity indices				
	TSS (ºBrix)	TA (g/L)	pH	TSS (ºBrix) / TA (g/L	TSS (ºBrix) x pH
111	22.1	6.22	3.60	35.5	286
112	21.2	8.45	3.29	25.1	229
113	21.1	5.94	3.63	35.5	278
114	21.7	7.34	3.65	29.6	289
115	21.5	6.72	3.53	32.0	268
121	19.6	7.16	3.45	27.4	233
122	21.3	5.43	3.68	39.2	288
123	21.7	6.34	3.59	34.2	280
124	20.7	5.84	3.65	35.4	276
125	21.5	6.36	3.59	33.8	277
211	17.9	5.98	3.64	29.9	237
212	20.2	5.96	3.67	33.9	272
213	18.1	5.84	3.63	31.0	239
214	18.8	5.92	3.62	31.8	246
215	19.0	6.08	3.69	31.3	259
221	19.3	6.30	3.38	30.6	220
222	21.1	6.32	3.46	33.4	253
223	23.0	6.71	3.47	34.3	277
224	21.8	6.45	3.45	33.8	259
225	21.4	6.86	3.42	31.2	250
311	25.5	5.62	3.55	45.4	321
312	26.2	5.70	3.63	46.0	345
313	24.8	5.66	3.67	43.8	334
314	22.1	5.44	3.55	40.6	279
315	21.7	5.50	3.74	39.5	304
321	15.9	5.83	3.28	27.3	171
322	15.5	4.92	3.37	31.5	176
323	13.6	4.14	3.48	32.9	165
324	17.2	4.16	3.53	41.3	214
325	20.1	5.65	3.41	35.6	234
411	19.5	6.66	3.47	29.3	235
412	21.5	7.05	3.48	30.5	260
413	20.7	6.21	3.57	33.3	264
414	21.2	6.28	3.48	33.8	257
415	19.8	6.53	3.43	30.3	233
421	21.4	6.44	3.51	33.2	264
422	21.5	5.94	3.61	36.2	280
423	20.6	6.74	3.51	30.6	254

424	20.7	6.00	3.62	34.5	271
425	20.5	6.42	3.59	31.9	264
511	23.3	6.04	3.67	38.6	314
512	23.4	7.07	3.47	33.1	282
513	22.5	7.42	3.27	30.3	241
514	23.2	6.02	3.67	38.5	312
515	23.6	6.77	3.58	34.9	302
521	22.7	6.67	3.46	34.0	272
522	22.4	6.28	3.48	35.7	271
523	23.2	6.52	3.43	35.6	273
524	22.8	5.95	3.45	38.3	271
525	23.1	6.01	3.52	38.4	286
611	21.6	6.41	3.66	33.7	289
612	21.7	6.36	3.75	34.1	305
613	22.2	5.99	3.72	37.1	307
614	22.2	5.98	3.69	37.1	302
615	22.0	5.77	3.69	38.1	300
621	21.9	5.80	3.66	37.8	293
622	21.8	5.96	3.80	36.6	315
623	19.0	6.14	3.74	30.9	266
624	20.8	5.78	3.78	36.0	297
625	20.8	5.66	3.80	36.7	300
711	19.6	3.94	3.96	49.7	307
712	19.5	4.01	3.94	48.6	303
713	18.7	4.15	3.91	45.1	286
714	19.5	4.30	3.93	45.3	301
715	19.0	4.67	3.94	40.7	295
721	20.1	4.82	3.76	41.7	284
722	20.0	4.60	3.85	43.5	296
723	20.7	4.80	3.84	43.1	305
724	20.7	5.04	3.75	41.1	291
725	21.5	4.60	3.81	46.7	312
811	20.5	4.76	3.87	43.1	307
812	21.0	5.38	3.78	39.0	300
813	21.2	4.82	3.79	44.0	305
814	21.0	4.87	3.79	43.1	302
815	21.5	5.60	3.74	38.4	301
821	21.2	5.63	3.75	37.7	298
822	21.4	5.37	3.77	39.9	304
823	21.5	4.92	3.81	43.7	312
824	21.7	5.50	3.71	39.5	299
825	21.7	4.97	3.79	43.7	312
911	19.7	4.72	3.82	41.7	287
912	19.6	3.88	3.88	50.5	295

913	20.9	4.68	3.82	44.7	305
914	21.1	4.20	3.86	50.2	314
915	20.9	4.14	3.86	50.5	311
921	19.7	5.88	3.64	33.5	261
922	18.1	6.40	3.63	28.3	239
923	20.1	7.04	3.61	28.6	262
924	20.6	7.20	3.61	28.6	268
925	19.0	7.84	3.59	24.2	245
931	18.3	6.18	3.62	29.6	240
932	18.4	6.47	3.63	28.4	242
933	18.7	6.68	3.63	28.0	246
934	20.0	6.16	3.70	32.5	274
935	18.8	6.23	3.58	30.2	241
1011	17.1	6.58	3.70	26.0	234
1012	18.3	6.91	3.82	26.5	267
1013	16.5	6.73	3.73	24.5	230
1014	16.8	7.41	3.69	22.7	229
1015	16.0	6.88	3.69	23.3	218
1021	19.1	5.78	3.73	33.0	266
1022	20.7	5.22	3.70	39.7	283
1023	20.1	5.24	3.78	38.4	287
1024	19.6	5.31	3.68	36.9	265
1025	20.3	4.78	3.85	42.5	301

[a]Number indicates site, panel, vine.

Appendix 3.19 Berry chemistry and classic maturity indices in 2009.

Vine[a]	Grape chemical parameters and classic maturity indices				
	TSS (ºBrix)	TA (g/L)	pH	TSS (ºBrix) / TA (g/L	TSS (ºBrix) x pH^2
111	19.9	11.3	3.27	18.0	213
112	18.3	9.8	3.30	19.0	199
113	18.3	9.0	3.42	20.0	214
114	17.4	10.2	3.34	17.0	194
115	19.1	9.2	3.28	21.0	205
121	16.6	9.2	3.37	18.0	189
122	18.3	10.4	3.39	18.0	210
123	17.5	10.3	3.32	17.0	193
124	17.2	10.8	3.31	16.0	188
125	19.0	9.3	3.42	21.0	222
211	21.1	10.8	3.33	20.0	234
212	20.7	11.0	3.29	19.0	224
213	20.5	10.8	3.33	19.0	227
214	19.7	11.8	3.36	17.0	222
215	20.6	10.3	3.45	20.0	245
221	22.1	9.5	3.38	23.0	252
222	20.4	10.4	3.30	20.0	222
223	19.0	9.8	3.41	19.0	221
224	19.1	10.8	3.32	18.0	211
225	20.1	9.9	3.33	20.0	223
311	21.1	11.5	3.26	18.0	224
312	20.9	10.8	3.30	19.0	228
313	21.0	11.2	3.29	19.0	227
314	20.1	10.8	3.28	19.0	216
315	20.7	9.4	3.36	22.0	234
321	21.4	8.9	3.40	24.0	247
322	21.9	9.8	3.37	22.0	249
323	22.8	11.0	3.33	21.0	253
324	20.3	9.6	3.36	21.0	229
325	21.0	11.1	3.25	19.0	222
411	19.4	10.1	3.38	19.0	222
412	19.6	10.1	3.36	19.0	221
413	21.3	10.1	3.36	21.0	240
414	18.7	10.2	3.30	18.0	204
421	20.3	10.3	3.36	20.0	229
422	20.0	11.5	3.36	17.0	226
423	20.4	11.2	3.39	18.0	234
424	22.8	9.3	3.47	25.0	275

425	21.5	10.8	3.33	20.0	238
511	20.2	9.5	3.39	21.0	232
512	22.7	10.3	3.36	22.0	256
513	20.2	9.5	3.38	21.0	231
514	21.6	10.5	3.38	21.0	247
515	22.6	11.1	3.37	20.0	257
521	21.8	10.4	3.32	21.0	240
522	21.3	11.2	3.34	19.0	238
523	22.1	11.2	3.32	20.0	244
524	22.8	12.0	3.34	19.0	254
525	22.0	10.1	3.36	22.0	248
611	21.1	10.0	3.40	21.0	244
612	21.0	9.6	3.43	22.0	247
613	21.0	9.1	3.46	23.0	251
614	20.7	10.1	3.41	21.0	241
615	21.1	9.4	3.46	22.0	253
621	20.7	9.2	3.45	23.0	246
622	21.2	9.4	3.50	23.0	260
623	21.4	9.6	3.42	22.0	250
624	21.5	9.0	3.47	24.0	259
625	19.6	9.6	3.48	20.0	237
711	21.1	6.7	3.86	32.0	314
712	20.6	6.6	3.81	31.0	299
713	20.3	7.3	3.85	28.0	301
714	20.8	6.1	3.86	34.0	310
715	20.7	7.0	3.82	30.0	302
811	21.4	7.0	3.79	31.0	307
812	21.0	8.1	3.72	26.0	291
813	21.8	8.3	3.63	26.0	287
814	21.4	7.3	3.69	29.0	291
815	21.9	7.7	3.76	29.0	310
821	21.7	7.1	3.90	30.0	330
822	22.0	6.7	4.01	33.0	354
823	21.4	7.2	3.97	30.0	337
824	21.7	7.0	3.96	31.0	340
825	21.7	6.9	4.00	31.0	347

[a]Number indicates site, panel, vine.

Appendix 3.20 Average temperature in 2008.

Site	Temperature (ºC)										
	May	June	July	August	September	October[a]	Anthesis -30 DAA	Anthesis -50 DAA	50 DAA-15 Oct	65 DAA-15 Oct	Season[b]
2008											
1	12.11	20.73	21.18	19.01	16.94	11.93	20.61	20.90	16.43	15.97	17.44
2	13.18	21.92	22.19	19.75	17.35	12.55	21.32	21.71	17.14	16.43	18.30
3	13.18	21.92	22.22	20.13	17.58	12.52	22.48	21.76	17.38	16.63	18.42
4	12.94	21.37	22.31	19.59	17.07	12.23	20.97	21.51	16.91	16.18	18.08
5	12.94	21.37	22.31	19.59	17.07	12.23	20.97	21.51	16.91	16.18	18.08
6	12.94	20.98	21.78	19.88	17.37	12.50	20.25	21.05	17.21	16.46	18.03
7	13.04	20.39	23.62	21.14	19.08	14.52	23.27	23.10	18.72	18.03	19.01
8	13.04	20.39	23.62	21.38	19.20	14.73	22.22	22.96	18.91	18.50	19.09
9	11.69	19.69	21.95	20.42	18.01	12.73	21.29	21.40	17.59	16.83	17.77
10	11.69	19.69	21.79	20.07	17.91	12.66	21.20	21.17	17.13	16.82	17.65
2009											
1	13.73	17.27	19.09	20.30	15.34	8.24	18.18	18.97	15.66	13.76	16.36
2	14.59	18.08	19.98	20.96	16.07	9.11	19.25	19.86	16.39	14.53	17.16
3	14.06	17.98	20.17	21.11	16.28	9.38	19.37	20.00	16.57	14.76	17.17
4	14.63	17.75	19.77	20.84	15.55	8.91	18.94	19.63	16.07	14.15	16.93
5	14.63	17.75	19.77	20.84	15.55	8.91	18.94	19.63	16.07	14.15	16.93
6	14.63	17.80	20.02	21.13	16.04	9.42	19.10	19.83	16.49	14.64	17.18
7	13.98	17.85	21.30	23.06	17.61	13.21	20.03	21.04	18.62	17.12	18.28
8	14.06	17.87	21.40	23.05	17.63	13.29	20.13	21.12	18.64	17.15	18.32

[a]Calculated from 1 October to 15 October.

[b]Calculated from 1 May to 15 October.

Appendix 3.21 Growing degree days in 2008 and 2009.

Site	Growing Degree Days (GDD)[a]										
	May	June	July	August	Septembe r	October[b]	Anthesis – 30 DAA	Anthesis – 50 DAA	50 DAA - harvest	65 DAA - harvest	Season[c]
200											
1	77	322	347	310	233	49	318	549	524	379	1337
2	105	358	390	315	233	53	341	599	553	398	1453
3	105	358	393	338	250	56	161	605	594	427	1499
4	98	341	400	309	233	55	336	595	551	398	1436
5	98	341	400	309	233	55	336	595	551	398	1436
6	98	330	368	319	241	60	309	569	573	414	1426
7	101	312	424	341	274	70	366	652	618	449	1523
8	101	312	424	357	284	79	366	586	721	438	1558
9	69	291	375	333	261	43	340	574	532	372	1371
10	69	291	370	323	245	44	339	565	512	419	1342
200											
1	164	220	277	326	184	28	240	445	469	286	1199
2	184	246	296	342	203	32	266	543	549	364	1303
3	213	287	304	280	208	33	311	592	557	371	1324
4	179	237	319	339	192	37	254	474	527	344	1304
5	179	237	319	339	192	37	254	474	527	344	1304
6	190	248	306	348	196	36	258	483	544	371	1324
7	138	227	348	410	240	121	303	575	605	401	1484
8	141	238	346	407	244	124	306	581	608	404	1500

[a]Calculated using a base of 10°C.
[b]Calculated from 1 October to harvest.
[c]Calculated from 1 May to harvest.

Appendix 3.24 Photosynthetic photon flux density in 2008.

	Photosynthetic photon flux density ($\mu mol/m^2s^{-1}$)[a]					
Site	August	September	October[b]	50 DAA-15 Oct	65 DAA- 15 Oct	Aug-Oct[c]
1	-[d]	-	-	-	-	-
2	14616	10098	4799	27547	20325	29513
3	14339	9875	4657	26827	19782	28872
4	14224	10138	4624	27161	20254	28987
5	14224	10138	4624	27161	20254	28987
6	14477	9965	4584	27232	19995	29027
7	16409	11302	5149	28446	19779	32861
8	16827	11236	5035	29965	23005	33098
9	12568	10303	4794	24925	17213	27665
10	15816	10852	5056	27009	21634	31723

[a]Calculated as the sum of the daily average photosynthetic (400-700nm) photon flux density.
[b]Calculated from 1 October to harvest.
[c]Calculated from 1 August to 15 October.
[d]Data unavailable.

Appendix 3.25 Photosynthetic photon flux density in 2009.

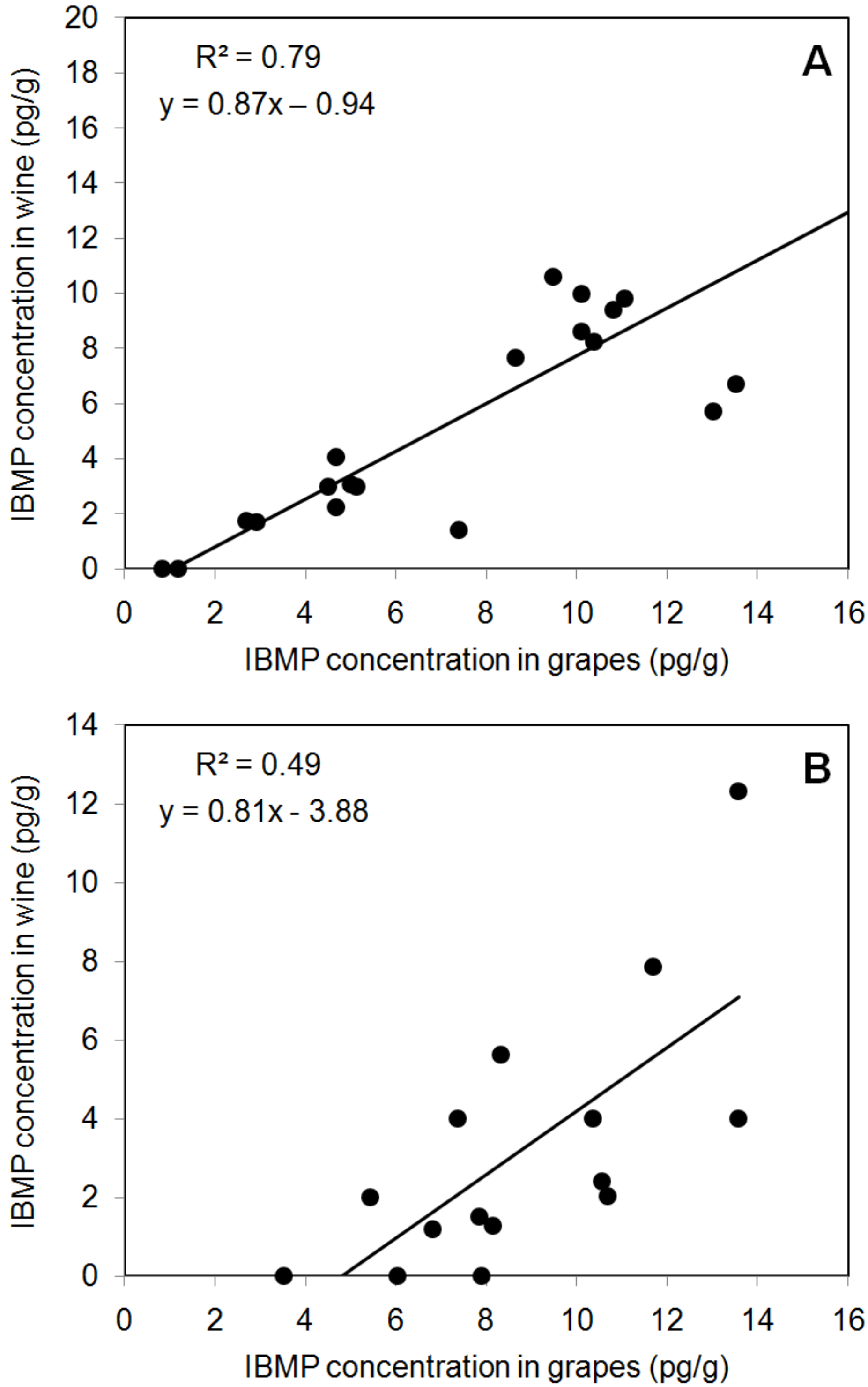
Site	Photosynthetic photon flux density (μmol/m^{2}s^{-1})[a]										
	May	**June**	**July**	**August**	**September**	**October[a]**	**Anthesis-30 DAA**	**Anthesis-50 DAA**	**50 DAA-15 Oct**	**65 DAA-15 Oct**	**Season[b]**
1	15611	14760	15524	13924	10441	3270	15296	25314	24533	17269	73531
2	16072	14508	16053	14051	10593	3168	15722	25897	24681	17649	74444
3	15931	14712	15792	13996	10650	3183	15615	25676	24714	17637	74264
4	15081	13573	14924	13302	9678	2969	14652	24150	22978	16305	69526
5	15081	13573	14924	13302	9678	2969	14652	24150	22978	16305	69526
6	14494	13183	14514	12974	9422	2822	14049	23439	22286	15811	67409
7	13301	12108	16715	14161	11646	3882	15207	25250	26948	19546	71813
8	13219	12062	16865	14449	11488	3922	15383	25552	27000	19472	72005

[a]Calculated as the sum of the daily average photosynthetic (400-700nm) photon flux density.
[b]Calculated from 1 October to 15 October.
[c]Calculated from 1 May to 15 October.

Appendix 3.24 Rainfall in 2008 and 2009.

Site	Rainfall (mm)										
	May	June	July	August	September	October[a]	Anthesis-30 DAA	Anthesis-50 DAA	50 DAA-harvest	65 DAA-harvest	Season[b]
2008											
1	31	42	86	229	50	26	48	123	292	94	464
2	49	32	148	114	69	29	55	180	200	128	441
3	36	40	94	129	70	40	11	145	223	136	408
4	29	85	100	76	172	16	92	166	253	201	478
5	29	85	100	76	172	16	92	166	253	201	478
6	29	77	128	101	123	27	82	211	239	167	495
7	64	52	103	90	168	15	15	125	263	189	491
8	64	52	103	125	128	0	15	112	253	132	471
9	68	96	147	85	58	9	96	240	110	82	472
10	68	96	123	84	79	35	109	215	144	137	492
2009											
1	90	148	113	166	47	3	119	190	179	94	568
2	61	157	71	35	14	11	118	157	54	32	349
3	63	185	66	85	39	28	127	164	144	112	466
4	63	96	42	99	55	17	83	108	167	114	373
5	63	96	42	99	55	17	83	108	167	114	373
6	87	106	77	134	53	17	117	165	194	128	473
7	58	154	158	71	45	85	178	215	181	154	572
8	85	154	158	13	45	84	178	199	140	131	540

[a]Calculated from 1 October to harvest.
[b]Calculated from 1 May to harvest.



Appendix 3.25 Linear correlation between IBMP concentration (5-vine panel average) in grapes and IBMP concentration in resulting wine in **(A)** 2008 and **(B)** 2009.

GLOSSARY

Anthesis – The period at which a flower is open and fully functional; usually denoted in grapes as 50% capfall

Basal leaf removal – manual or mechanical removal of leaves growing near the base of shoots

Grapevine canopy – collective arrangement of the grapevine shoots, leaves, and fruit

Chlormequat – plant growth regulator that blocks gibberellic acid biosynthesis

Crop load – ratio of crop to vine size, usually expressed as yield/pruning weight or leaf area/pruning weight

Shoot tipping – removal of ≤ 8 cm of the shoot tip

Veraison – the onset of ripening; usually denoted by color change in fruit, berry softening, and sugar accumulation

Vigor - relative vine growth rate; vigorous vines are noted as having shoots with long internodes, large leaves, and persistent laterals